ASPECTS OF POLLUTION IN FALSE BAY, SOUTH AFRICA (WITH SPECIAL REFERENCE TO SUBTIDAL POLLUTION)

BY

CARL DAVID RUNDGREN

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under the supervision of Professor A.C. Brown.

DECLARATION

I certify that this thesis results from my original investigation, except where acknowledged, and has not been submitted for a degree at any other university.

C.D RUNDGREN

DEDICATION

This thesis is dedicated to my wife, Charlotte and my parents, Eric and Pat, for their love and support.

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ABSTRACT

False Bay is the largest (circa 1000km^2) natural, coastal embayment on the South African coastline and is located between latitudes 34°04'S and 34°23'S and longitudes 18°26'E and 18°52'E at the southern tip of Africa, near Cape Town, South Africa.

The semi-enclosed nature of the bay makes it unsuitable as a 'sink' for all the contaminated urban stormwater run-off and the greatly increased pollution loads entering the bay.

All pollution point sources entering False Bay were identified and described, and some of these selected for detailed study, the emphasis being on the impact of some individual discharges on the subtidal macrofauna.

The similar biotic characteristics of three subtidal study sites in the region of the Steenbras Water Treatment Plant discharge indicate that the general turbidity and lower salinity characteristics of eastern False Bay are more likely to be responsible for the impoverished diversity near the outfall rather than the aluminium content of the discharge.

Toxicity experiments on the bivalves <u>Choromytilus meridionalis</u>, <u>Mytilus galloprovincialis</u> and <u>Perna perna</u> using alum and ferric sludge indicate that there are no significant short-term sub-lethal toxic effects on the rocky shore bivalves and that decreased salinities in the immediate region of the outfall (as a result of the freshwater stream input) may have a more deleterious effect.

A study of eighteen subtidal sites in False Bay indicated that overall densities of subtidal macro plastic debris were low, but that there are some 'hot spots' where densities are relatively high viz., Kalk Bay, Stranfontein, Mnandi, Monwabisi and Gordon's Bay. Colonising of debris by benthic organisms does occur, mostly on white plastic. Most of the debris consisted of plastic packaging from local land-based sources, indicating that it originates from wind blown litter left by beachgoers. The highest density at the Sunnycove Control Site occurred in January during the peak holiday season.

A longer term (three years) study of the subtidal environment in the vicinity of the Marine Oil Refiners outfall pipe indicated that the lack of subtidal macro fauna is more likely due to the harsh environmental conditions (abrasion and smothering) rather than the pollution impact of the outfall. This is confirmed by the abundant, healthy and diverse community on the nearby wreck of the Clan Stuart (1917) which indicates a stable ecosystem.

The complexity of False Bay - its unique topography, bathymetry, meteorology - make it difficult to attain a true climatic or average circulation. This lack of a consistent conceptual overview of the False Bay physical circulation is a short-coming that needs to be urgently addressed if the dangers of pollution inputs are to be accurately assessed. An overall management policy for False Bay should be urgently formulated and an officially constituted body with legislative power is needed if holistic management of the bay is to be achieved and such a prime recreational asset preserved for future generations.

CHAPTER ONE

GENERAL INTRODUCTION

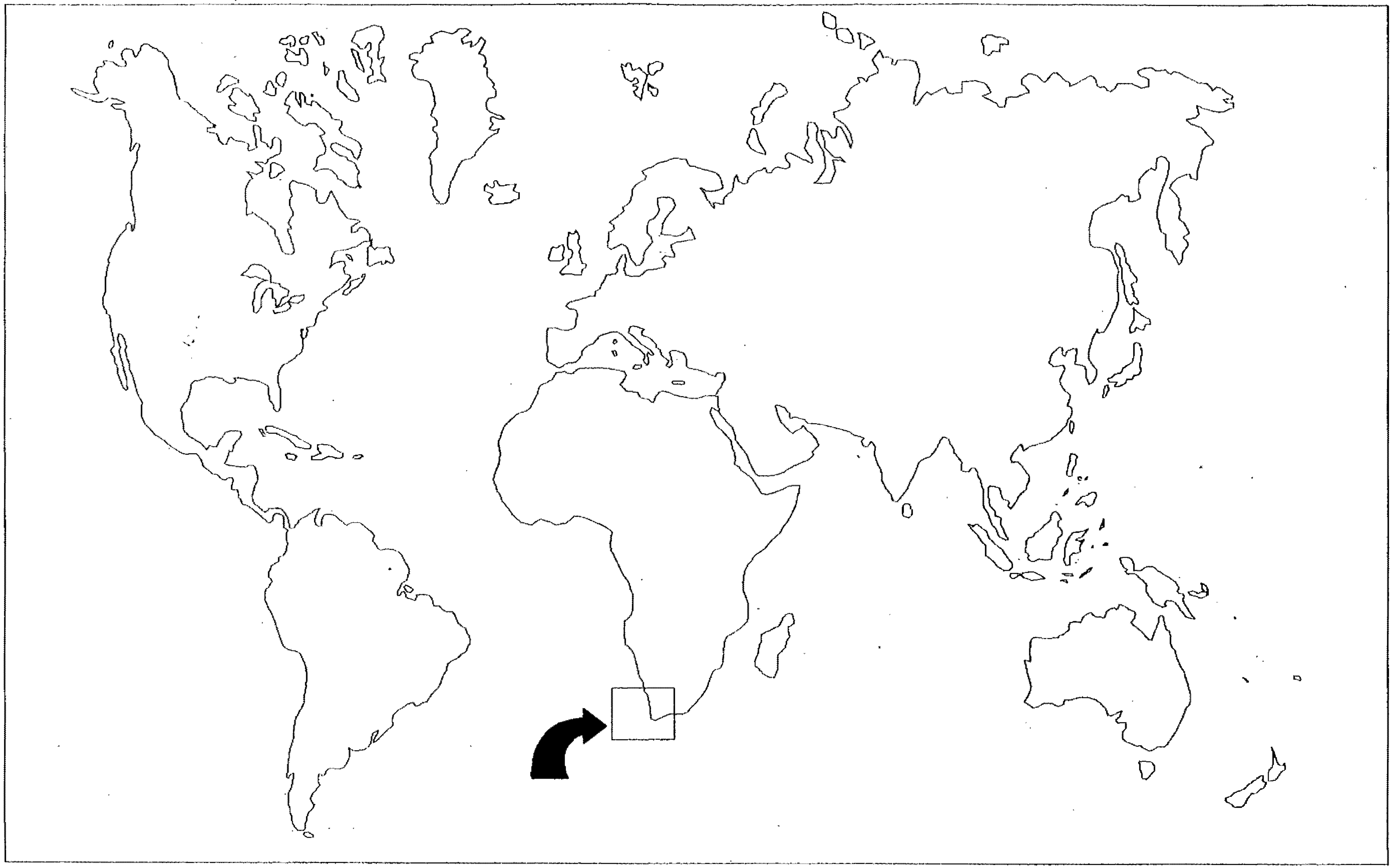

Fig. 1.1: Map of the World showing location of False Bay

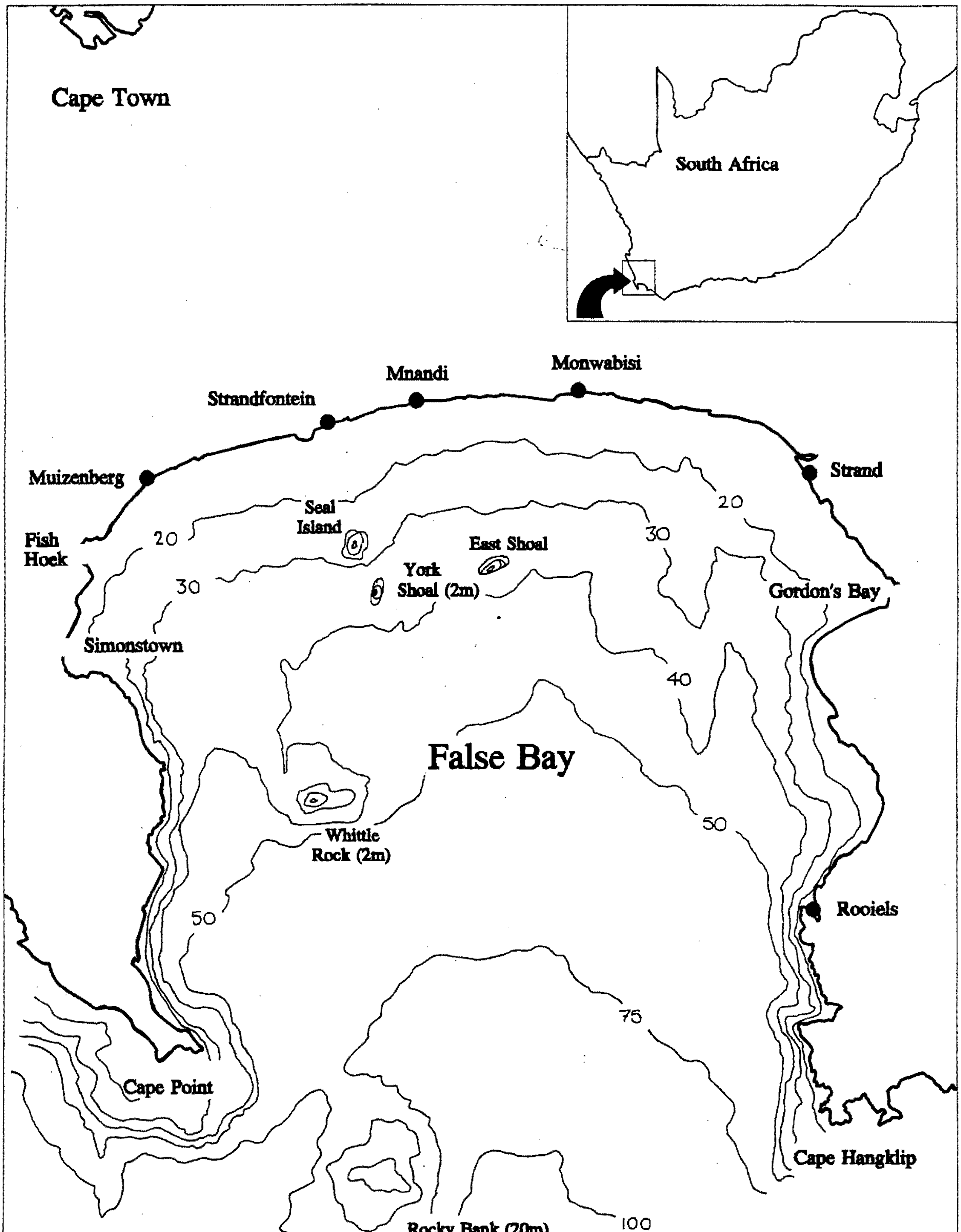

Fig. 1.2: Topography of False Bay
(After Gründlingh & Largier, 1991)

INTRODUCTION

False Bay is a large, natural, coastal embayment located between latitudes 34°04'S and 34°23'S and longitudes 18°26'E and 18°52'E at the southern tip of Africa, near Cape Town, South Africa.

The surface area of the bay has been variously stated in the literature as between 900 - 1000km^2 but Spargo (1991) recently reports a more accurately determined area as being between 1082 - 1091km^2. This makes it the largest bay on the South African coastline. It is much larger than other bays such as Walvis Bay (99km^2), Saldanha Bay (72km^2) and Richards Bay (26km^2) (Gründlingh et al., 1989). False Bay is almost square with each side roughly 30 - 35 kilometres in length with the southern entrance to the Atlantic about 35km wide.

Topographically the bay is bounded by the Cape Peninsula Mountain Chain in the west, the Hottentots-Holland and Kogelberg in the east, and the broad, sandy basin of the Cape Flats in the north, extending to the Tygerberg Hills. The shoreline is largely rocky on the west and east with precipitous slopes and vertical cliffs, sandy in the north between Muizenberg and Gordon's Bay (characterised by an almost unbroken stretch of beach interrupted by a cliff of coastal aeolianites at Swartklip) and the southern entrance to the sea is dominated by the high rocky headlands of Cape Point in the west and Cape Hangklip in the east, respectively. About 26% of the shore consists of mixed rock and sand (Brown et al., 1991a). The hydrographic environment is complex as False Bay is situated in a region of overlap of the warm Agulhas Current and the cold Benguela Current (Cliff, 1982). The warmer and more variable temperatures of False Bay compared to Table Bay have been recognised for some time (see Gilchrist, 1902), but these effects are promoted by the extent and shallowness of the bay rather than the influence of the Agulhas Current. The bay cannot be regarded as having any estuarine characteristics for it is large and has negligible fresh water inflow. Gründlingh et al. (1989) suggest that there are no significant basin scale horizontal salinity gradients in the bay since the total annual river run-off amounts to only 1% of the bay volume. Furthermore the mouth is too large for it to have the characteristics of a marine lagoon. The wide mouth of the bay permits free exchange with the open ocean of nutrients and the chemical constituents necessary for life processes. It also allows passage into the bay of numerous marine organisms ranging from phytoplankton to whales (Newman, 1980). Thus False Bay cannot be considered as an isolated entity but is best regarded as part of the broader oceanic coastline where there is some shelter from the full effects of swell and storm, particularly in winter (Morgans, 1959).

The general depth gradient runs from north to south with the depth in the outer bay reaching about 85m between Cape Point and Cape Hangklip (Fig. 1.2). The depth contours are relatively smooth over large parts of the western half of the bay and almost all of the southern bay, but the eastern section is characterised by a highly irregular bottom. Rock pinnacles and reefs also interrupt the smoother, sediment covered part of the bay around Roman Rocks, Seal Island, York Shoal, East Shoal and Whittle Rock. In the entrance to the bay there are two submerged rocky reefs. Rocky Bank is a large, isolated reef reaching a shallowest depth of 22m, and Hangklip Ridge forms an extended reef that stretches from Cape Hangklip, south-westwards for at least 20km (Fig. 1.2). The deeper parts of the bay are thus marked by two constricted passages, one between Cape Point and Rocky Bank and the other between Rocky Bank and Hangklip Ridge.

These channels merge with the open shelf at a depth of about 120m. False Bay is therefore the southern extension of the large valley that continues into the Cape Flats (Flemming, 1982).

The morphology of the bay and its surrounding hinterland closely reflects the solid geology (Glass, 1980) and is relatively simple. It consists basically of only three different lithostratigraphic units, viz., Malmesbury Shales (MS), Cape Granite (CG) and Table Mountain Sandstone (TMS). The oldest rocks in the area belong to the Malmesbury Group and they underlie the eastern part of the Cape Flats and the eastern part of the bay. This results in a somewhat flat topography. The Cape Peninsula Granite was intruded into the Malmesbury Group 610 million years ago and this granite underlies the western part of the Cape Flats and the western part of the bay. It also produces a rather flat topography but it occasionally outcrops as isolated round masses e.g. at Roman Rock, Whittle Rock and Seal Island (Fig. 1.2). Resistant quartz arenites of the Table Mountain Group were subsequently deposited in the shallow tidal sea on top of the older Malmesbury Group and Cape Peninsula Granite about 450 million years ago. The mountains along the western and eastern margins of the bay exist because these quartz arenites are very resistant to weathering processes. Almost all the re-enterents and little bays along the eastern and western coasts of False Bay can be related to faults or folds in these Table Mountain Group arenites, e.g. Smitswinkel Bay, Rooiels and Fish Hoek Bay. Beneath the waters of False Bay TMS arenites also produce positive relief, e.g. Rocky Bank and Hangklip Ridge. Thus it can be seen that the entire bay is diagonally divided into granite and shale with the occurence of sandstone virtually restricted to the perimeters of False Bay. Although the southern geographical limit of False Bay has often been taken to be a line between Cape Point and Cape Hangklip, from a geological point of view it can be seen that the bay as a system really extends a good deal further south than this (Glass, 1980).

An accumulation of fossil bones found in the Swartklip cliffs on the north shore of False Bay, which are believed to have been left by hyenas during one of the last great ice ages (Upper Pleistocene), has allowed a reconstruction of what the area looked like twenty thousand years ago. At this time the shoreline extended beyond Cape Point and Cape Hangklip and today's False Bay was low lying temperate grassland with the extinct giant Cape horse (Equus capensis) and giant buffalo (Pelorovis antiquus) together with more familiar animals such as the quagga (Equus quagga), white rhinoceros (Ceratotherium simum), wildebeest (Connochaetes gnou) and springbok (Antidorcas marsupialis) roaming this huge plain. With the remains of these grazing animals, bones of hippopotamus (Hippopotamus amphibius), clawless otter (Aonyx capensis), water mongoose (Atilax paludinosus) and reedbuck (Redunca arundinum), were also found, indicating that streams or fresh water pans must have punctuated this broad, open plain (Kench, 1984). This contention is supported firstly by the absence of marine animals in the sample and secondly by the dominance of grazing over browsing ungulate species which neither occur historically nor in western Cape Holocene deposits. Further support for this palaeonenvironmental setting is provided by organic rich deposits found intertidally along the Strandfontein coast. These deposits are thought to represent accumulations of organic remains of vegetation growing around a pool or stream which formed while the sea level regressed. A lump of this lignatized material contained the mandible of a modern southern reedbuck (Redunca arundinum) thus placing the deposit within the Upper Pleistocene (Avery, 1980). With the end of the ice age the bay came into existence again and it appears that early man, as indicated by a skeleton discovered in 1927 at Peers Cave (which overlooks the sandy valley linking Fish Hoek and Kommetjie at the southern end of the Cape Peninsula), was living in the area at least as far back as fifteen thousand years ago (Kench, 1984).

The occurrence of tidal fish traps in False Bay located at Buffels Bay, Bordjiesrif and Kogelbaai are known to have been utilised both prehistorically and recently in some areas. The traps are thought to relate to the present sea level, specifically to the last 2000 years during which pastoralists (Hottentots or Khoikoi) are known to have been in the south-western Cape (Avery, 1980).

The Portuguese navigator, Bartholomew Dias, is attributed with being the first European to have sighted the bay in 1488, and the name False Bay in fact originates from an early Portuguese name for Cape Hangklip, Cabo Falso (False Cape), so called because many early navigators returning from the East mistook Cape Hangklip for Cape Point, thereby sailing into False Bay instead of Table Bay (Spargo, 1991).

For almost four hundred years subsequent to the first European sighting of the bay, its immediate environs experienced comparatively little development. During this century the steady growth of the city of Cape Town and its suburbs led to increasing, but unspectacular, human pressure on the margins of False Bay. This changed dramatically in 1986 with the lifting of the influx control laws, one of the cornerstones of the Government's apartheid policy. Almost overnight a flood (500 per day) of Africans from the Ciskei and Transkei began to arrive on the Cape Flats in the area now known as Khayelitsha. The population of Khayelitsha (1990) was officially estimated at 320 000 (although this is almost certainly conservative) and it is expected that by the year

2000 close to 1.5 million people will be living along the False Bay coastline between Muizenberg and the Strand (EMATEK, 1991). This continuing population explosion on the Cape Flats has led to astronomically increased demands on the bay for recreation, fishing and other human activities.

Today there are many public amenities on the shores of False Bay and the numerous beaches are famous holiday resorts. For aesthetic reasons, as well as for the protection of public health, it is imperative that high standards of cleanliness should be maintained on beaches and in surf zones. This has assumed added importance since the South African tourist industry and its concomitant recreation demand is expected to increase considerably in the near future because of diplomatic initiatives and South Africa's acceptance back into the global village. This means that recreational activities and their impact will intensify substantially. The Western Cape receives over 800 000 visitors annually, over half of whom arrive during the peak holiday season (December to mid January) and most of the remainder during the second peak (mid January to the end of April) (CAPTOUR, pers. comm.). False Bay has moderately warm water (12-21°C) which makes it more attractive for water sports and general beach activities than the cold, upwelled waters of the West Coast (10-16°C). In a study of shoreline utilisation conducted during the peak holiday periods (December and January) Van Herwerden & Bally (1989) found that peak utilisation of the shoreline is concentrated on sandy beaches, Muizenberg having one of the highest densities, with a mean number of 2444 visitors per kilometre (the study was conducted between 13h00 - 15h00 on fine days when beach attendances were expected to be at their maximum).

Up until now only the 'First World' part of the South African population has really utilised recreational facilities but as the less privileged sectors grow in affluence their impact on recreational areas is increasing rapidly. Domestically, recent political reforms will lead to further changes in socioeconomic patterns in South Africa and, as living standards improve, mobility and leisure time will increase for a large proportion of the population. This will obviously create added pressure on the False Bay coastline since this is a traditionally favoured recreational and holiday site.

Together with the major urbanisation phase, the current population of 2.6 million in the Cape Town Metropolitan area is expected to double by the year 2012 (Metropolitan Transport Planning Branch 1986). It has been estimated that Greater Cape Town may have a population of between 8.2 and 11.7 million by the year 2040 (Weekend Argus 03.06.1989).

An escalating population not only generates greater sewage loads but also means increased development of both housing and recreation facilities. The extension of hard surfaces in developed areas leads to more urban storm water run-off. Sanitation systems (sewage collection, treatment and disposal) and storm water drains are devised to reduce and eliminate adverse environmental and public health consquences of these wastes, since the major proportion of fresh-water inputs to built up areas leaves it as contaminated waste water. This problem is compounded by the very nature of the growing population on the north shore of False Bay. Most of the people live in informal or squatter settlements without proper sanitation systems. As a result much of the waste invariably ends up in the storm water which in turn flows into False Bay. Hence this combination of population growth, housing development and recreational demand poses an ever increasing threat to the waters of False Bay since it faces major increases in levels of pollution from not only sewage but also river and storm water run off, especially during the first floods of the rainy season.

Growing concern about the pollution of False Bay has given rise to numerous studies (see Atkins, 1970; NRIO, 1982; EMATEK, 1991). Individual studies have focussed on point sources of pollution entering the bay (Rundgren, 1987); rivers (Bickerton, 1982; Cliff & Grindley, 1982; Grindley, 1982; Heinecken et al., 1982; Morant & Grindley, 1982; Heinecken, 1982a, 1982b; Bartlett & Hennig, 1982; Heinecken et al., 1983); industrial effluent discharges (Eagle, 1976; Bally et al, 1980; Brown, 1979, 1980, 1983a, 1983b and 1989); stormwater (Brown et al, 1991b); hydrocarbons (Moldan, 1991). Although a large amount of data has been gathered on pollutants entering False Bay, scant attention has been paid to the subtidal effects of pollution on the marine fauna or flora.

The object of this thesis is to examine some aspects of subtidal pollution in False Bay with the aim of providing both a baseline data set for future reference (particularly in the case of macro-plastic debris) and to examine the effects of some pollution discharges on the subtidal fauna.

Each of the following chapters of the thesis is written as a discrete entity. Chapter Two surveys and examines the various point sources of pollution entering False Bay. Chapter Three considers the impact of a specific discharge on the subtidal fauna and Chapter Four examines the effects of various pollutants on rocky shore bivalve molluscs. Chapter Five is a synoptic survey of subtidal macro-plastic debris, and discusses the temporal and spatial variations in plastics distribution in relation to current movements. Chapter Six investigates the longer term effects of a specific discharge on the subtidal marine environment in the immediate vicinity of an outfall. Chapter Seven discusses the general circulation patterns which are central to any study on pollution in False Bay, and the concluding chapter, Chapter Eight, is a general synthesis which considers the management implications and makes some recommendations for the holistic management of False Bay.

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CHAPTER TWO

INVESTIGATION AND LOCATION OF POINT SOURCES OF POLLUTANTS ENTERING FALSE BAY

INTRODUCTION

The majority of the treated waste water genenerated by the growing population of the Cape Town Metropolitan area is directed to the shores of False Bay (see Eagle, 1980). Most of these waste flows are discharged into the surf zone of the bay through rivers, treated sewage outlets and storm water outlets. The increasing urban development and recreational utilisation of the False Bay shoreline has led to calls for wise management and realistic advanced planning (see Gasson, 1980). As a result the Steering Committee for Marine Disposal in Priority Areas, convened by the Department of the Environment Affairs, selected False Bay as a priority area in 1982. This resulted in a status report on pollution in False Bay (see NRIO, 1982), which summarised a series of separate reports which dealt with river studies (see Bickerton, 1982; Cliff & Grindley, 1982; Grindley, 1982; Heinecken et al, 1982; Morant & Grindley, 1982; Heinecken, 1982a and 1982b; Bartlett & Hennig, 1982), Marine chemistry and biology (see Eagle, 1982), marine geoscience (see Flemming, 1982), coastal engineering and sewage forecasts (see Gasson & MacKinnon, 1982). Pollution loadings into False Bay, particularly of very poor quality stormwater run-off (see Brown et al., 1991), greatly increased with the explosive growth of high density, mostly low income settlements along the northern shoreline and resulted in False Bay again being chosen as a priority area for investigation in 1986. As a preliminary exercise, it became necessary to identify and map all point sources of pollution entering False Bay.

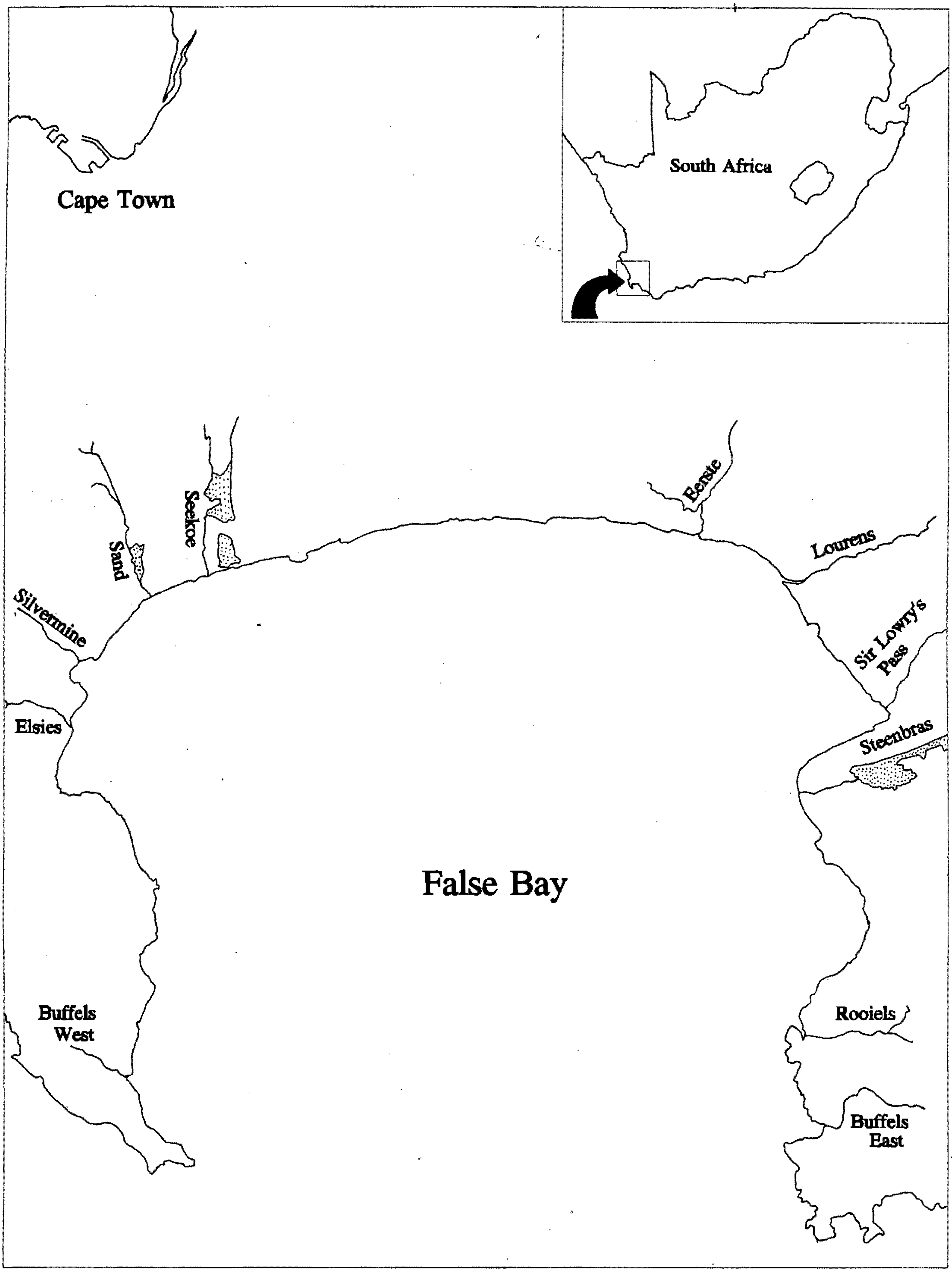

Fig. 2.1: Location of major rivers entering False Bay

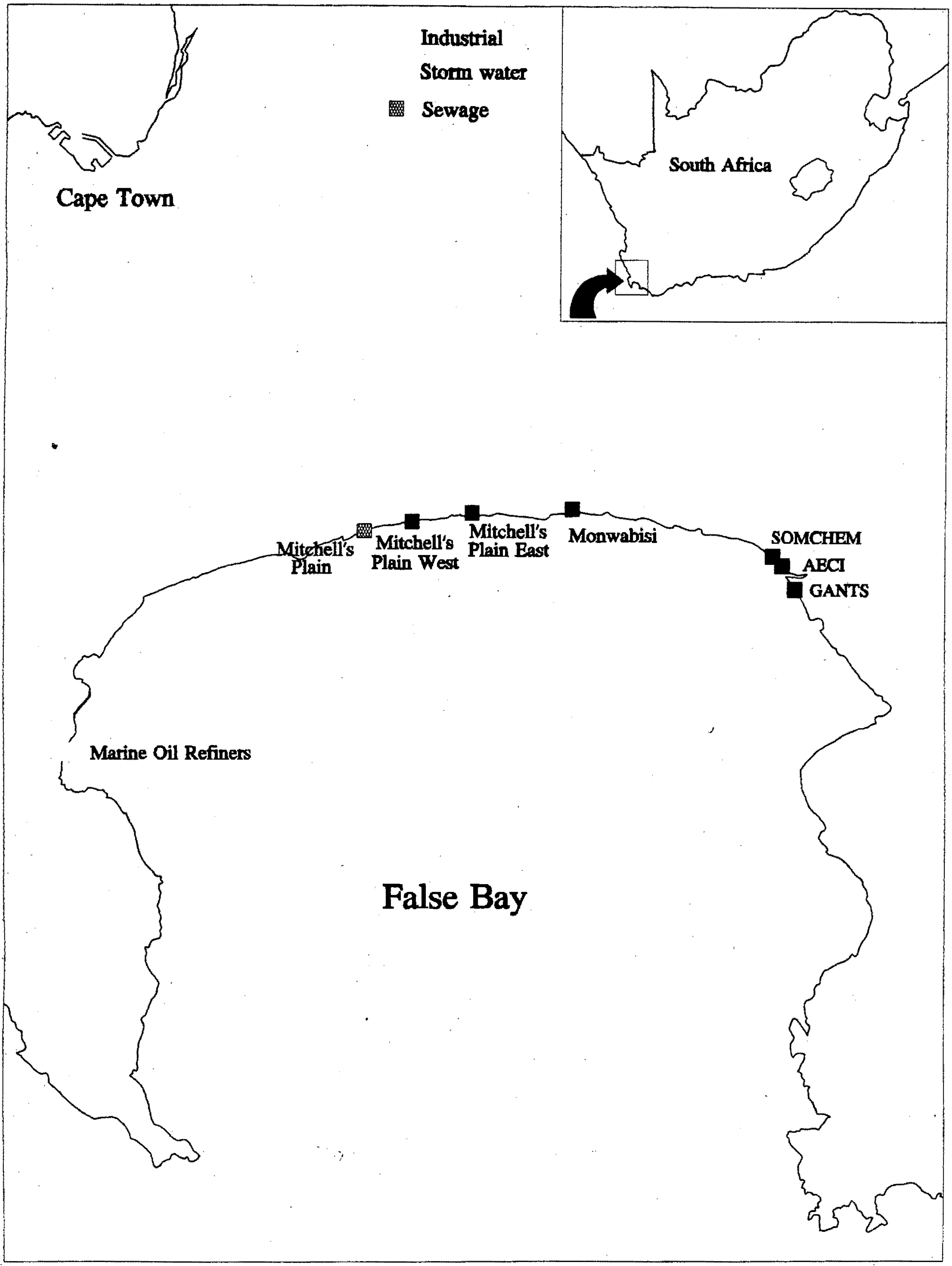

Fig. 2.2: Location of major sewage, industrial and stormwater discharges into False Bay

Table 2.1: Estuaries and rivers entering False Bay (Nov/Dec 1986)

RIVER	1:50 000 TOPOGRAPHICAL SHEET	CO-ORDINATES OF RIVER MOUTH	LOCAL AUTHORITY CONTROLLING MOUTH	ACCESS	WIDTH AT MOUTH (m)	DEPTH AT MOUTH (m)	FLOW	REMARKS
Buffels (West)	3418 AD & AB	34°19'S 18°28'E	Cape Divisional Council	Internal road in Nature Reserve and then walk 200m along beach	2.0	0.05	Weak	Strong odour possibly due to Restaurant sewage overflow
Elsies	3418 AB & AD	34°10'S 18°26'E	Simonstown Municipality	Main Rd. (Cape Town to Simonstown) crosses river at mouth	-	-	Zero	Not flowing into sea
Silver-mine	3418 AB & AD	34°07'S 18°27'E	Cape Town City Council & Fish Hoek Municipality	Main Rd. crosses river at its mouth near Clovelly Station	2.0	0.10	Weak	
Sandvlei	3418 AB & AD	34°06'S 18°29'E	Cape Town City Council	Beach front road cuts canal 200m from mouth	-	-	Zero	Not flowing into sea
Seekoe	3418 BA	34°06'S 18°30'E	Cape Town City Council	Coastal road from Muizenberg to Swartklip crosses canal 200m from mouth	10.0	0.30	Mod. - Strong	Canal 15m wide discharges onto beach
Eerste	3418 BB	34°05'S 18°46'E	Stellenbosch Divisional Council	N2 to Macassar and along beach	5.0	0.15	Weak	SOMCHEM security clearance required for part of estuary. Extensive back shore lagoon.
Lourens	3418 BB	34°06'S 18°49E	Stellenbosch Divisional Council & AECI	Beach road along Strand beach front crosses river 400m from mouth	2.0	0.10	Weak	AECI security clearance required for mouth

Table 2.1 (Cont.): **Estuaries and rivers entering False Bay (Nov/Dec 1986)**

RIVER	1:50 000 TOPOGRAPHICAL SHEET	CO-ORDINATES OF RIVER MOUTH	LOCAL AUTHORITY CONTROLLING MOUTH	ACCESS	WIDTH AT MOUTH (m)	DEPTH AT MOUTH (m)	FLOW	REMARKS
Sir Lowry's Pass	3418 BB	34°09'S 18°52'E	Gordon's Bay Municipality	Beach Road crosses river 200m from mouth	2.0	0.10	Weak	
Steen-bras	3418 BB	34°12'S 18°49'E	Caledon Divisional Council	Gordons Bay - Hangklip crosses river 200m from mouth	3.0	0.10	Weak	Sea pushes up mouth ± 300m. Freshwater input at time of survey minimal
Rooiels	3418 BD	34°18'S 18°49'E	Caledon Divisional Council	Coastal road from Gordons Bay - Hangklip crosses river at mouth	5.0	0.20	Moder-ate	Construction of new road and bridge extension contributing to pollution in terms of rubble and building material
Buffels (East)	3418 BD	34°20'S 18°50'E	Caledon Divisional Council	Main coastal road Gordons Bay - Hangklip crosses river 1.5km from mouth. Access via road into Pringle Bay 500m south of bridge	2.0	0.10	Moder-ate	15.1.87 not flowing into sea. Extensive backshore lagoon in existence.

Table 2.2: Effluent point sources entering False Bay (Nov/Dec 1986)

LOCATION	1:50 000 TOPOGRAPHICAL SHEET	LOCAL AUTHORITY	ACCESS	DIAMETER OF PIPE	FLOW	REMARKS
Buffels Bay	3418 AB & AD	Cape Divisional Council	Nature reserve internal road	-	-	Concreted pipe runs in to sea next to boat ramp and tidal pool. Discharges raw effluent from ablution block
Millers Point	3418 AB & AD	Simonstown	Main coastal road	0.10	-	Appears to come from ablution block
Millers Point	3418 AB & AD	Simonstown	Main coastal road	-	-	Sewage pump substation
Rocklands Point	3418 AB & AD	Simonstown	Main coastal road	-	-	Sewage substation and overflow
Oatland Point	3418 AB & AD	Simonstown	Main coastal road	-	-	Sewage pumping substation and overflow outlet
Froggy Pond	3418 AB & AD	Simonstown	Main coastal road	0.10	-	Ablution block and rusted pipes from sewage substation
Boulders	3418 AB & AD	Simonstown	Main coastal road	-	-	Sewage pumping substation - broken pipes and overflow from tanks
Boulders	3418 AB & AD	Simonstown	Main coastal road	0.20	-	Sewage pumping substation and overflow
Coles Point	3418 AB & AD	Simonstown	Main coastal road	0.20	-	Sewage pumping substation and overflow outlet
Mackerel Bay	3418 AB & AD	Simonstown	Main coastal road	0.20	-	Marine oil refiners industrial effluent outlet
Shelly Beach	3418 AB & AD	Simonstown	Main coastal road	-	-	Rusted pipes and septic tank
St. James	3418 AB & AD	Cape Town	Main coastal road	0.20	-	Broken steel pipes effluent oozing from below house
Mitchells Plain	3418 BA	Cape Town Divisional Council		0.60	Moderate	Flows across beach into sea. At sea 30m wide x 0.10m deep. 'Polluted Water' sign
Mitchells Plain	3418 BA	Cape Town Divisional Council	Strandfontein - Mnandi coastal road	Canal 5.0	Moderate	5.0m wide x 0.10m deep at sea. Canal adjoins parking area

Table 2.2 (Cont.): Effluent point sources entering False Bay (Nov/Dec 1986)

LOCATION	1:50 000 TOPOGRAPHICAL SHEET	LOCAL AUTHORITY	ACCESS	DIAMETER OF PIPE	FLOW	REMARKS
Mitchells Plain	3418 BA	Cape Town Divisional Council	Strandfontein-Mnandi coastal road	2x1.2	Moderate	Flows across beach into sea. At sea 3.0m wide x 0.10m deep. 'Polluted Water' sign
SOMCHEM	3418 BB	SOMCHEM	SOMCHEM internal roads	3x0.1	-	SOMCHEM security clearance required
SOMCHEM	3418 BB	SOMCHEM	SOMCHEM internal roads	5x0.1 1x 0.075	-	SOMCHEM security clearance required
AECI	3418 BB	AECI	AECI internal roads	0.40 culverts	-	2.0m wide x 0.15m deep streambed sampled and monitored by AECI. AECI security clearance necessary
Lourens Estuary	3418 BB	Strand	Strand beachfront road	-	-	* Gant's food effluent pipe. Fruit pips washed up on beach to west of pipe on AECI side of fence
Gordons Bay	3418 BB	Gordons Bay	Gordons Bay Beachfront road	0.1	-	
Gordons Bay	3418 BB	S.A. Navy	Gordons Bay Beachfront road	-	-	Under concrete inside Gordons Bay Naval College fence. Navy have been told to connect to sewage works.
Gordons Bay	3418 BB	Gordons Bay	R44 coastal road next to Naval beacon	stream bed 2.0m wide 0.10 deep	Moderate	

* The Gants outfall which discharged to the east of the estuary at the time of the original survey (Nov/Dec 1986) is no longer in operation and the discharge has now ceased.

Table 2.3: Stormwater point sources entering False Bay (Nov/Dec 1986)

LOCATION	1:50 000 TOPOGRAPHICAL SHEET	LOCAL AUTHORITY	ACCESS	DIAMETER OF PIPE (m)	FLOW	REMARKS
Smitswinkel Bay	3418 AB & AD	Cape Town Divisional Council	Main coastal road from Simonstown to Cape Point. Access on foot down hillside	0.5 est.	Trickle	Small stream with slight trickle flows down valley
Rumbly Bay	3418 AB & AD	Simonstown	Main coastal road from Simonstown to Cape Point	2 x 0.45 1 x 0.20	Zero	Stormwater pipes
Froggy Pond	3418 AB & AD	Simonstown		0.40	Zero	Stormwater pipe
Seaforth	3418 AB & AD	Simonstown		0.20	Zero	Stormwater pipe
Coles Point	3418 AB & AD	Simonstown		-	Zero	3x10cm pipes next to jetty
Simonstown Station	3418 AB & AD	Simonstown		1.00	-	Stormwater
Long Beach	3418 AB & AD	Simonstown		-	-	Stormwater
Long Beach	3418 AB & AD	Simonstown		-	Trickle	Small stream
Mackeral Bay	3418 AB & AD	Simonstown		0.50	-	Stormwater
Mackerel Bay	3418 AB & AD	Simonstown		0.50	-	Stormwater
Mackerel Bay	3418 AB & AD	Simonstown		2 x 0.50	-	Stormwater
Mackerel Bay	3418 AB & AD	Simonstown		0.30	Zero	Stormwater
Glencairn	3418 AB & AD	Simonstown		-	Blocked	Stormwater
Quarry Rock	3418 AB & AD	Simonstown		1 x 1.00 1 x 0.30	-	Stormwater
Fish Hoek	3418 AB & AD	Fish Hoek		1.50	-	Stormwater
Fish Hoek	3418 AB & AD	Fish Hoek		1.50	Zero	Stormwater
Clovelly	3418 AB & AD	Fish Hoek		0.20	Zero	Steel pipe - stormwater?
Clovelly	3418 AB & AD	Fish Hoek		0.45	Zero	Steel pipe - stormwater?

Table 2.3 (Cont.): Stormwater point sources entering False Bay (Nov/Dec 1986)

LOCATION	1:50 000 TOPOGRAPHICAL SHEET	LOCAL AUTHORITY	ACCESS	DIAMETER OF PIPE (m)	FLOW	REMARKS
Kalkbay	3418 AB & AD	Cape Town		0.60	Zero	Stormwater
Kalkbay Harbour	3418 AB & AD	Cape Town		0.55	Zero	Stormwater
Dalebrook	3418 AB & AD	Cape Town		0.55	Trickle	Next to tidal pool
Danger Beach	3418 AB & AD	Cape Town		0.60	Zero	Stormwater
Danger Beach	3418 AB & AD	Cape Town		0.45	Zero	Stormwater
Danger Beach	3418 AB & AD	Cape Town		0.60	Zero	Stormwater concrete
Danger Beach	3418 AB & AD	Cape Town		0.60	Zero	Stormwater concrete
Bailey's Cottage	3418 AB & AD	Cape Town		0.60	Trickle	Stormwater
Bailey's Cottage	3418 AB & AD	Cape Town		0.60	-	Stormwater - next to subway under railway line
Neptune's Corner	3418 AB & AD	Cape Town		0.70	Zero	
Neptune's Corner	3418 AB & AD	Cape Town		0.70	Trickle	Black mussel shells on beach
Strandfontein Pavilion	3418 BA	Cape Town	Coastal Road	1.30	Zero	Culvert
Strandfontein Pavilion	3418 BA	Cape Town	Coastal Road	0.35	-	Several stormwater pipes to west of pavilion
Strandfontein Pavilion	3418 BA	Cape Town	Coastal Road	0.75	-	Stormwater
Mitchell's Plain	3418 BA	Cape Town	Coastal Road	Canal 5 wide x 0.10 deep	Strong	Investigation and sampling needed to determine pollution status
Swartklip	3418 BA	Cape Town	Coastal Road	0.40	Zero	Stormwater
Macassar	3418 BB	Cape Town	Coastal Road	0.40	Zero	Stormwater
AECI	3418 BB	AECI	AECI internal road	0.40	Zero	2.0m wide x 0.15 deep sampled and monitored by AECI

Table 2.3 (Cont.): Stormwater point sources entering False Bay (Nov/Dec 1986)

LOCATION	1:50 000 TOPOGRAPH-ICAL SHEET	LOCAL AUTHORITY	ACCESS	DIA-METER OF PIPE (m)	FLOW	REMARKS
Strand	3418 BB	Strand	Coastal Road	0.70	Zero	Stormwater pipe across beach
Strand	3418 BB	Strand	Coastal Road	0.70	Zero	Stormwater pipe across beach
Strand	3418 BB	Strand	Coastal Road	Stream bed 4.0 wide	-	Depth indeterminable due to tidal input
Gordons Bay	3418 BB	Gordons Bay	Coastal Road			Stormwater pipeline across beach into sea 200m S of Sir Lowry's Pass River
Gordons Bay	3418 BB	Gordons Bay	Beach front road	0.30	Trickle	
Gordons Bay	3418 BB	Gordons Bay	Beach front road	0.40	Trickle	
Gordons Bay	3418 BB	Gordons Bay	Beach front road	0.30	Dry	
Gordons Bay	3418 BB	Gordons Bay	Beach front road	0.25	Trickle	
Gordons Bay	3418 BB	Gordons Bay	Beach front road	0.50	Dry	
Gordons Bay	3418 BB	Gordons Bay	Beach front road	0.50	Dry	
Boskloof	3418 BB	Caledon	R44 coastal road	-	*	Stream bed 24.11.86 1.0m wide x 0.20m deep. 15.01.87 virtually dry - trickle
Mermaid Pool	3418 BB	Caledon	R44 coastal road	Stream bed 3.0 wide 0.20 deep	Moder-ate	Stream bed flowing into sea
Pringle Bay	3418 BD	Caledon	Pringle Bay beach front road	-	Trickle	Marsh seepage

* 24.11.86 moderate, 15.01.87 trickle

Table 2.4: Miscellaneous observations: Phytoplankton blooms, unidentified pipes, litter, new and proposed construction

LOCATION	1:50 000 TOPOGRAPHICAL SHEET	LOCAL AUTHORITY	ACCESS	REMARKS
Bordjirif	3418 AB & AD	S A Navy	Cape Point Nature Reserve	Concrete pipe into sea from fenced off military area
Seaforth	3418 AB & AD	Simonstown	Main coastal road	2 x rubber pipes - black lightning flash on yellow background
Zeekoevlei	3418 BA	Cape Town C.C.	Coastal road	Phytoplankton bloom
Macassar	3418 BB	Cape Town C.C.	Coastal road	Phytoplankton bloom
Gordons Bay	3418 BB	Strand	Coastal road	Severe littering problem on beach possibly due to current eddies in this corner of False Bay. Building rubble and debris.
Gordons Bay	3418 BB	Strand	Coastal road	as above
Gordons Bay	3418 BB	Strand	Coastal road	as above
Gordons Bay	3418 BB	Gordons Bay	Coastal road	as above
Steenbras Mouth	3418 BB	Caledon Div. Council	R44 Coastal road	New construction of buildings on North bank at mouth
Dappat Se Gat	3418 BB	Caledon Div. Council	R44 Coastal road	Wooden latrine huts and litter evident
Koeelbaai	3418 BB	Caledon Div. Council	R44 Coastal road	Picnic sites and litter
Sparks Bay	3418 BB	Caledon Div. Council	R44 Coastal road	Proposed tidal pool and litter evident
Die Kruis	3418 BD	Caledon Div. Council	R44 Coastal road	Latrines, picnic sites and litter evident
Hangklip	3418 BD	Caledon Div. Council	Road south of Hangklip Hotel	New Fleur homes cluster development of holiday homes under construction

Plate 2.1: The canalised mouth of the Sand estuary showing the rubble weir which helps to maintain the water level in Sandvlei for recreational purposes

Plate 2.2: The artificially created mouth of the Seekoe which acts as the outfall for the discharge of effluent from the Cape Flats Waste Water Treatment Works

Plate 2.3: Mitchell's Plain sewage effluent outfall onto the beach

Plate 2.4: Retaining pond for Mitchell's Plain sewage outfall.

Plate 2.5: Mitchell's Plain West storm water outfall.

Plate 2.6: Mitchell's Plain East storm water outfall

Plate 2.7: Mitchell's Plain East storm water outfall showing the flow of storm water into False Bay

Plate 2.8: Monwabisi storm water outfall showing retention grid

Plate 2.10: Industrial effluent discharge into False Bay at Dido Valley, near Simonstown

Plate 2.11: Marine Oil Refiners industrial effluent discharge pipe showing the wreck of the Clan Stuart (1917) and Simonstown in the background

Plate 2.12: AECI security fence and Gants outfall pipe at Lourens River mouth

Plate 2.13: Lourens River mouth

DISCUSSION

Water Quality Criteria

One of the most important considerations in the management of marine ecosystems is to ensure that the quality of the sea water does not deteriorate beyond acceptable levels. Such Water Quality Criteria (WQC) are defined by Lusher (1984) as:

> "Those limits which must not be exceeded in order to maintain the chemical, physical and biological characteristics of a selected portion of the sea or estuary."

South African Water Quality Criteria are largely based on overseas criteria of the same nature and use faecal coliform as the indicator organism to assess the microbiological quality of the sea-water. The inference is that when faecal coliform counts in the sea-water are low, the presence of pathogens, such as viruses, in the sea water are presumed to be negligible, and consequently also the public health risk.

Water quality criteria using coliform and E. coli (i.e. coliforms from the human digestive tract) counts are used to describe quantitatively the minimum quality which will not only provide for but also protect any designated use. There is no single set of water quality criteria that is universally applicable and such water quality criteria are only a guide to enable realistic measures to be taken concerning the control of discharges. Criteria have to be set according to the use to which the water body is to be put and will also depend on local conditions. In False Bay, criteria governing public health are obviously critical, but criteria relating to nutrients, toxic metals and aesthetic aspects are also important. Increased pollution loadings due to rivers, stormwater drains, treated sewage outlets and industrial effluents discharging into False Bay must therefore be carefully monitored to prevent a decrease in the quality of sea-water in the bay.

Rivers

Rivers are prone to various forms of pollution, viz., bacteriological pollution which usually arises from sewage effluents; organic pollution, in the form of pesticides, herbicides, polychlorinated biphenyls (PCBs) and sewage (decomposition of the latter may also lead to depletion of oxygen in the water and sediments); and inorganic pollution in the form of trace metals or other compounds from specific industrial effluents, or from nutrients, coming from land run-off, fertilisers and sewage. There are eleven main rivers and estuaries which discharge into False Bay, viz., Buffels West, Elsies, Silvermine, Sand, Seekoe, Eerste, Lourens, Sir Lowry's Pass, Steenbras, Rooiels, Buffels East.

The Buffels West River is a small seasonal stream situated within the Cape Point Nature Reserve on the western side of False Bay (Fig. 2.1). It is a typical low pH, black water stream draining a small Table Mountain Sandstone (TMS) dominated catchment of approximately 3km^2 (Crowther, 1987). The river flows during the winter months from May to August. A tidal pool, ski-boat launching ramp, ablution block and braai areas are situated at Buffels Bay adjacent to the river mouth.

Since the entire catchment falls within the Cape of Good Hope Nature Reserve, the Buffels West is unlikely to pose a pollution threat to False Bay in the forseeable future.

The Elsies River, another seasonal stream, drains a TMS-dominated catchment with an area of approximately 18km² (Heinecken et al., 1982) and flows into the north-western corner of False Bay (Fig. 2.1). Stormwater from the residential areas of Da Gama Park and Glencairn situated within the catchment is discharged into the river. Occasional pump failures at the sewage pump station, situated at the river mouth, lead to sporadic discharges of raw sewage into the river course. Water not trapped by two dams in the upper catchment, plus any overflow, eventually runs into a Typha reed swamp at the lower end of the Elsies River Valley. The 'floc' from the reservoir water treatment plant is also discharged directly into the river below the dams. In terms of its pollution impact on False Bay Heinecken et al. (1983) consider the Elsies to be insignificant, contributing only small amounts of organic pollution (resulting from decaying kelp and terrestrial vegetation) and stormwater run-off. However, the recent expansion of Glencairn township may change this.

The Silvermine River is situated in the north-western corner of False Bay (Fig. 2.1) with a catchment of approximately 21km² (Heinecken et al. 1983). The lower section of the river receives most of the stormwater run-off from both the Clovelly and Fish Hoek residential areas, and the emergency overflows of sewage from both areas is discharged directly into the estuary in cases of pump malfunction. If the latter occurs the estuary is flushed out with fresh water and a commercial chlorine compound. The river flows throughout the year with periods of low flow in summer and spates in winter. The small seasonal lagoon at the mouth is opened artificially at the onset of the rainy winter season to prevent the build up of water and flooding of low lying developments at Fish Hoek. A large amount of litter and some faecal pollution occurs between the road and rail bridges which cross the river mouth. Littering at the mouth should also be controlled. High nutrient values, particularly nitrate and ammonia, have been found (Heinecken, 1982) probably as a result of storm water input and run-off from Clovelly Golf Course, which is fertilised regularly. A reed swamp below the golf course and the vegetation-lined river banks, which absorb a large proportion of the nutrients and pollutants entering upstream of the swamp, should be retained for their 'filtering' and 'purifying' functions. The pollution input of the Silvermine River into False Bay was considered negligible by Heinecken et al. (1983) but the continuing expansion of Fish Hoek township must be carefully controlled if degredation of the river is to be prevented.

The Sandvlei estuary is fed by four main streams, the Westlake, Keysers, Diep and the Sand/Langvlei Canal, which drain a catchment of approximately 80km^2 (Heinecken et al., 1983) and opens into the north-western corner of False Bay near Muizenberg (Fig. 2.1). The flow of water into Sandvlei increases with winter rains and decreases during dry summer months. As a result the mouth of the Sandvlei is artificially manipulated to regulate water levels in the vlei. During the latter part of winter, or periods of high rainfall, the mouth is opened to lower the water level. During the summer months when the mouth is closed, water levels in the vlei drop and water is pumped into the system from a series of radial wells situated near the mouth. The main pollutants entering the system are sewage, industrial effluent, stormwater and garbage. There are nine sewage pumping stations near Sandvlei and its influent streams, some of which are liable to overflow. Toxic effluents from industrial plants in the Retreat area include organic solvents and heavy metals which occasionally pollute the vlei as a result of accidents, negligence or malfunction of equipment. The run-off water from agricultural areas is likely to contain leached-out fertilisers and pesticides or pesticide residues. Low-income housing arèas and squatter camps, with little of no sanitation, are responsible for a considerable amount of garbage and faecal contamination entering the river system. Morant & Grindley (1982) report that the samples from various parts of the vlei contain less faecal coliforms than the influent streams and suggest that the higher salinity of Sandvlei is probably the main reason for this. However they report that water in Sandvlei does not comply with EEC Standards particularly in summer when greatest use is made of the vlei for recreation, and recommend that tighter controls on the water quality of influent streams is needed to ensure that there is no further deterioration and to ensure that the vlei will comply with EEC Standards throughout year. More recently Brown et al. (1991), in a study of nine sites along the north shore of False Bay, found sulphate and aluminium levels to be higher at Sandvlei than at any other site. Thus it would appear that Sandvlei poses an increasing pollution threat to False Bay.

The Seekoe is not a naturally formed estuary but consists of a canal constructed in 1942 to drain excess water from Rondevlei and Seekoevlei. It enters the upper north north-western corner of False Bay (Fig. 2.1) and the catchment of the Seekoe drainage system is 83.3km^2 (Heinecken et al., 1983). The outfall from the Cape Flats sewage works into the Seekoe Canal, constructed in 1962, dominates the run-off via the Seekoe Canal and is a major input of treated effluent into False Bay. Phytoplankton blooms (largely of Anaulus sp.) are often visible in the surf zone to the east and west of the canal mouth and this may be related to nutrient input into the surf zone from the effluent outfall or possibly due to sub-surface seepage from the oxidation ponds. McLachlan & Lewin (1981) often observed rich blooms after good rainfall and suggested that rainfall possibly increased groundwater seepage, thereby flushing more nutrients out of the intertidal, interstitial system. According to the ratio of harpacticoid copepods to nematodes (Hennig et al., 1982) the meiofaunal data indicate some perturbation by sewage, although the large numbers of harpacticoids suggest that interstitial beach sediments are well oxygenated. Brown et al. (1991) report that the loading rates of soluble reactive phosphorus, nitrate and nitrite - nitrogen, ammonia - nitrogen and dissolved organic carbon were the highest at the Seekoevlei outflow into False Bay. The Seekoe is considered to be of virtually no ecological value as an estuary and is a major source of treated sewage effluent input into False Bay.

The Eerste River estuary is situated in the upper north-eastern corner of False Bay (Fig. 2.1) and is fed by two rivers, the Eerste River itself and the Kuils River, with a combined catchment of 660km^2 (Heinecken et al., 1983). Although the Kuils River may originally have had a separate opening, it is now blocked with sand dunes which have forced it to join the Eerste in its lower reaches during periods of high flow. For the remainder of the time it drains into the Cape Flats Aquifer and forms marshy areas behind the coastal dunes (Wessels & Greef, 1980). The Macassar Sewage Works treating sewage from Macassar, Somerset West and Strand is located on the western bank of the estuary and discharges effluent into the estuary. The Bellville Municipal Works also discharges sewage effluent into the Kuils River. The influence of sewage effluent is minor during peak flows but very significant at times of low flow. Heinecken et al. (1983) report that water quality deteriorates significantly during summer and autumn because of organic pollution and low flow conditions. The seasonally reduced activities of riparian industries results in better water quality in winter and spring when these industries are not discharging effluents into the river and the flow increases. Outflow to the sea takes place mainly during the rainy winter season after which the mouth channel extensively meanders and is eventually closed off by the accretion of marine sediments. The results of pollution monitoring surveys of the Eerste River estuary (Bartlett & Hennig, 1982) indicated the presence of oil, fats and soap as well as various nutrients and metals. High concentrations of soluble reactive phosphorus and nitrate - and nitrite - nitrogen were found by Brown et al. (1991), probably as a result of treated sewage effluent. These pollutants are concentrated in the estuary while the mouth is closed, but are flushed out to sea by winter flooding of the system. Therefore they contribute to the concentration of pollutants in the north-eastern corner of False Bay.

The Lourens River flows into False Bay in the upper north-eastern corner (Fig. 2.1) and is a relatively small perennial river approximately 20km long with a catchment of 92km^2 (Cliff & Grindley, 1982). The estuary itself falls within the AECI (African Explosives and Chemical Industries) security fenced area. An emergency overflow pipe from a sewage pump station (situated adjacent to the estuary on its northern bank) opens into the estuary. The AECI main factory drain, which carries power station cooling water and stormwater from the AECI, Somchem and Triomf fertiliser plants and biologically treated sewage from the labourers compounds discharges into the sea approximately 1km north-west of the river mouth. This drain periodically discharges into the estuary and discharges of raw sewage into the estuary with subsequent fish kills have been recorded (NRIO, 1982). Pesticide and herbicide run off from the intensively farmed areas, stormwater discharge and dumping of debris such as bricks, rubble, concrete, tins, polystyrene and other plastics result in the river banks and the beach being strewn with litter. Cliff & Grindley (1982) report that samples collected near the mouth of the estuary showed very high E. coli and total coliform counts. The Lourens River estuary therefore contributes a significant amount of pollutants to False Bay, particularly when industrial discharges take place via estuary.

The Sir Lowry's Pass River enters False Bay in the north-eastern corner at Gordon's Bay (Fig. 2.1) and has a catchment area of approximately 23km² (Heinecken et al., 1982). The increasing use of herbicides and pesticides may present more serious pollution problems in the future, but Heinecken et al. (1982) consider that the river does not pollute False Bay and is unlikely to become a significant pollution source in the near future (Brown et al., 1991, found this to be the only river on the north shore with water of potable quality).

The Steenbras is an acid black-water river draining the eastern side of the Hottentots Holland mountain range and has a catchment of approximately 63km² (Heinecken et al., 1983). It flows into the Steenbras Dam, with the overflow entering False Bay on its east north-eastern side (Fig. 2.1). The water filtration plant for the dam (situated on the seaward side of Hottentots Holland mountains about midway between Gordon's Bay and the mouth of the Steenbras River), uses alum (aluminium sulphate) and other sulphates to coagulate fine particulate impurities which then form sediments. When the filters are back-washed, these sediments are flushed into False Bay below the filtration plant. Local sport divers have reported blanketing of the sea bed by flocculants in the area but no evidence of large scale aluminium enrichment was found in the sediment of the area (NRIO, 1982). The filtration plant does not appear to be a serious source of pollution in False Bay (see Chapter 3 for detailed investigation), and it would appear that the disturbance is an unaesthetic one rather than a pollution threat. Since the Steenbras and its catchment have been a major water resource for Cape Town since 1921 they can be considered to be insignificant as a source of pollution in False Bay.

The Rooiels River flows into the eastern side of False Bay (Fig. 2.1) and drains a TMS catchment of approximately 20km² (Heinecken et al., 1983). It is perennial with high flow rates in winter. Although the only form of pollution, at present, at the estuary is litter, lack of public toilets may lead to problems when large numbers of people visit the area. As the township develops, the run-off from septic tank soak-aways may also cause problems. However, it is unlikely that the Rooiels currently contributes any significant pollution to False Bay.

The Buffels East is an acid, black-water system which enters False Bay on its south-eastern side on the northern side of Pringle Bay (Fig. 2.1) and drains a catchment of approximately 23km². A survey of the physico-chemical characteristics of the Buffels estuary (see Heinecken et al., 1982) indicated that it is an unpolluted system and does not contribute pollutants to False Bay.

Effluent Point Sources

Almost all treated residential and industrial effluent and stormwater run-off are eventually discharged into False Bay. Consequently there is a large number of point-source inflows into the surf zone of False Bay, particularly on the north shore where most development is taking place. These include not only rivers (Fig. 2.1), but also stormwater drains, treated sewage outlets and industrial discharges (Fig. 2.2). With the rapid urbanisation of the north shore, a further deterioration in the water quality of the Cape Flats Aquifer, which provides substantial ground water seepage into False Bay, can be expected. In conjunction with increased point-source loadings of effluent (sewage, stormwater and industrial), this will lead to a marked reduction in the sea water quality of False Bay.

Treated Sewage Outfalls.

Of eleven treatment works, five are directly on the bay head and release treated water into the sea, while six are inland and release treated wastes into the Bottelary, Kuils and Eerste Rivers. The discharges of most concern are on the north shore: the Cape Flats Sewage Works which discharges treated effluent into the Seekoe Canal (Fig. 2.1); the Mitchell's Plain Treatment Plant which discharges directly into the surf zone via a small sewer at Strandfontein (Fig. 2.2); and the effluents from the Macassar and Zandvleit Sewage Treatment Works (the latter is expected to serve 800 000 people in its final stage, generating 120 000m^3 d^{-1} of treated sewage [Gardiner, 1989]), which discharge treated effluent near the mouth of the Eerste River and hence indirectly into the surf zone of False Bay (Fig. 2.1).

Brown et al. (1991) found nitrate and nitrite concentrations to be of concern at the Mitchell's Plain sewage outfall, and both nitrate, nitrite and phosphorus at the Seekoe and Eerste Rivers. Nutrient levels were also found to be highest at Seekoevlei. These high loading rates, particularly of nutrients, are a direct result of treated sewage effluent at Seekoevlei. Future high loading rates may also be expected at Monwabisi as Zandvleit sewage works receives increasing volumes of raw sewage. Viruses were also detected in the Mitchell's Plain sewage outlet at Strandfontein (Idema & Kfir, 1990).

Stormwater Outlets

Although there are numerous small outlets (400 - 700mm diameter) in the Muizenberg/Simonstown and Strand/Gordon's Bay corners of False Bay, these have relatively small catchments. The preliminary survey was carried out during the dry summer period (Nov/Dec 1986) when most stormwater point sources were dry or contribute very little flow into False Bay. This was particularly true in the Hangklip to Gordon's Bay section of the Bay, where virtually all the mountain streams were dry. These two areas obviously contribute considerably to the stormwater input into the Bay during the winter rainfall season. However, comparative lack of development in this area means that stormwater inputs should not contain such high pollution loadings as those entering the surf zone on the north shore. The major outlets of concern include the Sand, Seekoe, Eerste and Lourens Rivers plus the storm water effluent outfalls for the expanding, adjacent urban areas, viz.,

i) The Mitchell's Plain West outfall, located to the west of the Mnandi Pavilion, is a 5m diameter canal which drains part of the Mitchell's Plain area of the Cape Flats (Fig. 2.2).

ii) The Mitchell's Plain East outfall, located to the east of Mnandi Pavilion (Fig. 2.2), consists of two 1.2m diameter pipes which drain the suburb of Mitchell's Plain (middle to low income housing) and a small portion of Khayelitsha (low income/ subsistence housing).

iii) The Monwabisi outfall, located about 1300m east of Monwabisi tidal pool, drains most of the Khayelitsha township, and also receives sewage effluent from the new Zandvleit sewage works. The outfall aperture dimensions onto the shore are approximately 3m x 1.5m (Fig. 2.2).

Brown et al. (1991) found that worst quality stormwater entering the bay on the north shore was from the Mitchell's Plain West outfall. Monwabisi outfall also had low quality stormwater during the spate sampled and the quality is expected to further deteriorate as the development of the coastline and inland areas, such as Khayelitsha, continues. Increased flows and deteriorating quality can also be expected from the Eerste and Lourens Rivers as urbanisation proceeds in their catchments and stormwater is fed into the rivers. Brown et al. (1991) report that the following chemical parameters do not conform to the acceptable Water Quality Criteria: total suspended solids at Mitchell's Plain West, Monwabisi and Mitchell's Plain East outfalls; nitrate and nitrite concentrations at Mitchell's Plain East and Mitchell's Plain West; lead concentrations at both Mitchell's Plain West and Monwabisi (lead is a highly toxic cumulative poison common in industrial effluents); cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel and zinc levels at the Mitchell's Plain West outfall; and high nutrient values in the Cape Flats Aquifer. As the hard surface areas of stormwater catchments increase with further urban development, the storm water volume and loading rates will increase and thus daily loading rates at Monwabisi can be expected to at least equal, if not exceed, those at Mitchell's Plain West in the near future. Recent studies (Augoustinos & Kfir, 1990; Idema & Kfir, 1990; Wright, 1990; Brown et al., 1991) have highlighted the poor microbiological quality of stormwater run-off from both formal and informal residential developments, especially during rainfall periods after prolonged dry spells. Particularly high faecal coliform levels were found during storm events. It has been found that stormwater constitutes a greater total inflow of health related micro organisms than treated sewage effluents and river discharges. As a result water quality in the surf zone immediately adjacent to stormwater outlets is of poorer quality than that near treated sewage or river outlets. Viruses were detected in the sea water in the vicinity of the Mitchell's Plain East, Mitchell's Plain West and Monwabisi stormwater outfalls, and shell fish collected adjacent to Mitchell's Plain East storm water outlet were found to be unsuitable for raw consumption (Idema & Kfir, 1990). This is of critical concern since several epidemiological studies have shown the consumption of polluted shell fish to be an agent for viral infection in humans (Metcalf et al., 1970). In contrast, dissolved nutrient inputs were relatively low except for high nitrate levels causing minor enrichment immediately adjacent to the stormwater outlets.

Industrial Discharges

Although there are some minor industrial discharges, such as that of Marine Oil Refiners (see Brown, 1979, 1980, 1983a, 1983b, 1989) at Dido Valley near Simonstown, the three industrial discharges of importance are all situated in the vicinity of the Lourens River on the north shore of False Bay (Fig. 2.2). The African Explosives and Chemical Industries (AECI) are permitted to discharge industrial waste water into the Lourens estuary, although the effluent does not comply with the required criteria (Cliff & Grindley, 1982). When the estuary mouth is closed, the effluent goes directly to the sea by pipeline and the 'main factory drain'. Bartlett (1980) found that the presence of meiofauna was affected at this outfall but Augoustinos & Kfir (1990) found the microbiological quality of the water to be better than that of all the other outfalls on the north shore including rivers, sewage and stormwater outlets. The SOMCHEM complex discharges industrial effluent directly into the surf zone to the west of the Lourens estuary but little information is available on this input due to the restrictions of the Official Secrets Act (NRIO, 1982) and because of the security clearance necessary to enter the area. The Gant's Canning Factory discharges effluent into the sea via an outfall pipe next to the AECI security fence. Microbiological levels of this effluent were found to be the highest in False Bay, although the bacteria are probably not of human (faecal) origin. Bally et al. (1980) report that large numbers of viable bacteria, probably associated with the decaying matter in the effluent, are washed into the sea at the outfall pipe. While the effects appear to be mainly localised, some were detectable 175m down current of the outfall (decreased meiofauna, increased nitrites, nitrates). The effluent reduces the salinity significantly in the vicinity of the outfall and its nutrient content affects the seawater chemistry. Silicates, nitrates and nitrites are locally increased, while total phosphorous appeared to be low. Bacteria were abundant in the area affected by the effluent. The rapid decrease in numbers to either side of the outfall suggests both a rapid dilution and a rapid killing of the organisms. The sudden temperature drop (22.5°C to 18.3°C within a few metres) as well as the sudden increase in salinity probably combine to kill a high proportion of the organisms quite rapidly. This is in accordance with the findings of Faust et al. (1975), who found that the survival of coliform bacteria under estuarine conditions depends on the physico-chemical conditions of their aquatic environment. Many filter feeders feed largely on bacteria and Bally et al. (1980) suggest that the large mussel beds of Choromytilus meridionalis on the rocks immediately offshore and on the tidally submerged portions of the outfall pipe, filter out a considerable proportion of both live and dead bacteria from the seawater. Enzinger & Cooper (1976) have shown that marine ciliates are also important predators of coliform bacteria, and thus the combination of sudden environmental change, predation by ciliates and filtering of the water by mussels are the probable factors preventing any large build up of viable bacteria in the immediate area.

Low values of meiofauna at the outfall pipe and to the west indicate a general westward transport of effluent. The presence of a well developed anoxic black layer is probably caused by the resultant high organic loading and low numbers of meiofauna are therefore probably due to this de-oxygenation of the sediments. Bally et al. (1980) suggest that although an extended pipeline might improve dispersion, discharge into a sheltered bay might be less effective than discharge into the turbulent and well oxygenated surf zone. More recently (see EMATEK, 1991) the factory is reported to be closing down, although effluent is still being discharged.

Phytoplankton

The brown discolouration of the sea water in the surf zone in the vicinity of the Seekoevlei outfall and further east has elicited much public comment because the Cape Flats Sewage Works discharges its effluent into the surf along this stretch of shore. This discolouration, although aesthetically displeasing, is due neither to sewage nor other pollutants but is a completely harmless, natural phenomenon resulting from the 'blooms' of the non-toxic surf zone phytoplankton species, Anaulus australis. McLachlan & Lewin (1981) report that dense phytoplankton 'blooms' occurred along the northern shore of False Bay predominantly between Muizenberg and Strandfontein Point. At high densities these phytoplankton 'blooms' result in formations of stable scum on the sea surface. The colour of the scum ranges from light golden to dark brown (Table 2.5). Tapscott (1981) concluded from samples gathered near Muizenberg that the only organism present in large numbers and of sufficient size to account for the colouration was the diatom Anaulus birostratus.

Table 2.5: Median diatom cell counts for various groups (derived from Tapscott, 1981)

Water Colouration	Median Cell Count (ml^{-1})
Normal	40
Light brown	6000
Medium brown	12000
Dark brown	27000

The greatest numbers of diatoms were found to occur in the surface water film. It is apparent that dense 'blooms' of diatoms within the surf zone are a typical feature of some sandy beaches (McLachlan, 1983) and their abundance is attributable to their ability to tolerate and to continue to grow under extremes of temperature, salinity, light and nutrient levels. Lewins and Schaefer (1983) suggest that the following factors influence the occurrence and formation of diatom 'blooms':

i) The topography of the coast - a broad shallow surf zone required

ii) Winds - densest blooms accompany on-shore winds.

iii) Nutrient Supply - a readily available source of nitrogen.

iv) Rainfall - most known surf zone 'blooms' occur in high rainfall areas.

The visible 'bloom' appears to occur only when the physical conditions are right to cause the diatoms to congregate in one place, although Anaulus may be present at other times. The occurrence of Anaulus species has been recorded not only in South African waters (Heiden & Kolbe, 1928; Cholnoky, 1964; Giffen, 1971) but also in many other parts of world e.g. Sumatra and Antarctica (Wood, 1963) English Channel (Hendey, 1964), Mediterranean (Peragallo, 1897-1908). However Taylor (1964) did not record any species of Anaulus in his off-shore study of south-west Indian Ocean Phytoplankton. Grindley & Taylor (1970) report that 'red tides' characterised by the toxic species Gonyaulax polygramma, which is toxic to marine life, and non-toxic species such as Noctiluca are also frequently seen in False Bay. Through concentration and mass mortality the non-toxic species may cause oxygen depletion resulting in fish kills.

Although there is evidence to suggest that the occurrence of Anaulus 'blooms' along the False Bay shore is not initiated by the Cape Flats Sewage Works outfall (see NRIO, 1984), Brown & McLachlan (1990) suggest that Anaulus 'blooms' are dependent on nutrient inputs from the beach and from outfalls. Brown et al. (1991) report that the 'blooms' appear to have increased in extent in recent years and are now in evidence all along the north shore as far as the Eerste River. They suggest that this is indicative of the dramatically increased nutrient loadings from outfalls along the north shore. Although nutrient enrichment per se cannot presently be considered as a pollution problem in False Bay, (nutrient concentrations in the surf zone are always lower than nutrient levels measured in the bay during a naturally occurring upwelling event - see EMATEK, 1991), the increased discolouration of the sea water by the resultant Anaulus 'blooms' has serious implications for the tourist trade in what is a prime recreational area.

Litter

The greatest concentrations of litter on the shoreline are found between Gordon's Bay and the Strand, at Kalk Bay Harbour and at the Mnandi and Monwabisi and Strandfontein tidal pools. Much of this is disposable plastic packaging which is virtually immune to biodegradation. Ryan & Moloney (1990) suggest that inshore currents are responsible for most of the inter-beach variation in plastic abundance and that the densities of all types of plastic objects have increased significantly on South African beaches in recent years. This has profound implications for marine life (see Shaughnessy, 1980; Furness, 1983; Cawthorn, 1985; Laist, 1987; Fowler, 1987; Stewart & Yochem, 1987; Fry et al., 1987; Carr, 1987; Ryan, 1987, 1988a, 1988b; Ryan et al., 1988) particularly since the cleansing departments of local councils in the Cape Town area may reduce the frequency of garbage collection.

Waste Dispersal

The ability of the False Bay to accept waste depends on the rate of exchange of the water masses of the bay with the open ocean, and this can only take place through the southern side of the bay. The residence time of the water in False Bay was calculated to be 4-6 days in the summer but considerably longer in winter (Atkins, 1970). Hence the main mechanism of dispersion of effluent in False Bay is through turbulent action caused by waves, tides and currents, and a number of factors affect this:

i. The predominant current direction in the bay is clockwise and there are frequent eddies both clockwise or anti-clockwise in the Gordon's Bay area. Under such conditions waste material is deposited in this region.

ii. The bottom gradient is very gentle along the bay head and the water is shallow. Currents in the shallow water are slow and tend to be wind generated. Predominantly southerly winds give these currents a marked on-shore component which has been calculated to be as high as 70% on occasions (Atkins, 1970).

iii. Shallow water causes the waves to break further from the shore, increasing turbulent mixing.

Although currents are strongest in summer, thermoclines are also best developed in that season. Since disposed effluent will tend not to cross the thermocline, this effectively reduces the diluting capacity of the bay under such conditions. These factors point to a possible accumulation of nutrients and high organic wastes in the north-eastern corner of the bay which is likely to increase with the rapid urbanisation along the north shore. This is more likely to occur in winter when currents are weakest. Bartlett and Hennig (1982) concluded from meiofauna counts that effluent from the Eerste River as well as the rest of False Bay would end up in the Gordon's Bay area. The semi-permanent eddy there is unique and isolated from the rest of the bay. Atkins (1970) found the circulation to be either clockwise or anti-clockwise and previous studies have also shown that during calm (or northerly) wind conditions, warm surface water (usually associated with longer residence time and nutrient depletion) tend to accumulate in this section of False Bay (Atkins, 1970; Day, 1970; Grindley & Taylor, 1970). The circulation patterns in north-east False Bay are complex and influenced by the topography, upwelling, winds and tides etc. which cannot be described by measuring current patterns alone. An estimate of residence time is needed in order to give a more reliable indication of the pollution impact as well as the effect of future discharges into this area. The sediments at Gordon's Bay have slowly accumulated metals during the last few years possibly as a result of the general pollution of False Bay or increased algal production caused by upwelling in the south corner of Gordon's Bay (Marchand, 1932 and Grindley & Taylor, 1964 & 1970 have reported localised upwelling at Gordon's Bay).

CONCLUSIONS

The water quality of none of the rivers on the north shore (the Sand, Seekoe, Eerste, Lourens and Sir Lowry's Pass Rivers) complies with the South African Sea Water Criteria (Lusher, 1984) nor with the bacteriological limits of a revised set of guidelines recommended by Grabow et al. (1989) for direct contact recreation in sea water (see Augoustinos & Kfir, 1990). Mitchell's Plain sewage outfall is the only major sewage outfall discharging directly onto the beach and the water quality in the surf zone around the outfall is unacceptable for recreation purposes or for harvesting of shell fish according to the above criteria. The stormwater quality at the Kalk Bay, Strandfontein, Mitchell's Plain West, Monwabisi and Mitchell's Plain East outfalls are all also unacceptable. Of the industrial outfalls the Gant's effluent outfall was found to have the poorest water quality in False Bay, whereas that of the AECI outfall has the highest microbiological quality (Augoustinos & Kfir, 1990). The bacterial loading rates indicate that stormwater outfalls are the major contributers of microbiological pollution in False Bay because insufficient dilution is occurring and the sea water in the surf zone cannot accommodate the high loading rates. As a result the marine ecosystem is already being overloaded and the situation is likely to be further exacerbated as the development of Khayelitsha continues and the loading rates at the Monwabisi outfall increase and then exceed those of the Mitchell's Plain West outfall.

Clearly the impact of pollution on the marine environment along the north shore of False Bay is becoming critical and urgent action is required. Although the construction of an ocean outfall pipeline discharging beyond the surf zone would achieve the higher dilutions necessary to conform to the Water Quality Criteria for the South African Coastal Zone, False Bay is not ideally suited for such a pipeline because the nearshore areas of the bay are relatively shallow, the percentage of onshore currents is relatively high and False Bay itself has restricted water exchange since it is an enclosed bay. The secondary eddies in the Gordon's Bay and Fish Hoek embayments, together with the currents due to differential wave set up, are likely to result in the accumulation of pollution in the Gordon's Bay, Eerste River, Swartklip, Muizenberg and Simonstown areas. It is suggested that in order to reduce the pollution impact the following steps should be taken: stormwater should be initially diverted into holding or settling ponds prior to discharge into the bay; chemical and microbiological sampling of the major outfalls should be continued; littering should be more rigidly controlled; warning notices should be posted at impacted areas which have a clear health risk; and Water Quality Criteria should be strictly enforced for industrial effluents being discharged into False Bay.

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CHAPTER THREE

THE IMPACT OF THE STEENBRAS WATER TREATMENT PLANT DISCHARGE ON SUBTIDAL FAUNAL COMPOSITION

INTRODUCTION

Long term toxicity and bioaccumulation of metals from a number of sludges has been investigated by Franklin (1983), using various marine organisms. Slight evidence of uptake of Cu, Zn and Pb was obtained but no evidence of bioaccumulation of Hg or Cd. Metal accumulation in crustaceans (Jennings & Rainbow, 1979; White & Rainbow, 1986) has also been reported and barnacles are known to accumulate metals from solution (Rainbow, 1985, 1987). Chapman et al. (1988) found that silver tightly bound to sewage sludge could be accumulated by marine organisms directly or indirectly following ingestion, and suggested that other metals occurring in sludge (e.g. Zn, Cu, Pb, Cd, Hg) may also be accumulated. These results indicate that sludge is taken as a suitable food source and that metals associated with the sludge may be accumulated. Attatchment of sludge particles to body surfaces and subsequent ingestion of these organisms by larger predators may also be a significant route for the transfer of metals from sludge into marine organisms (see Preston & Portmann, 1981). Young & Pearce (1975) also report that the gills of crabs and lobsters exposed experimentally to sewage sludge became coated with a brown covering and accumulated detritus. The underlying tissues of these animals became necrotic and developed lesions. Young & Copalan (1975) report shell disease in shrimps possibly resulting from bacterial infections following erosion of the exoskeleton. Although the effects of these metals is well documented, there is scant information on the effects of aluminium in the marine environment, and Pantin (1982) in an extensive review of the effects of pollutants in the sea, including metals, fails to even mention aluminium. However it is known to be toxic to plants, invertebrates, fish and higher vertebrates, and Birchall (1990) reports that under certain circumstances concentrations as low as $5\mu mol.l^{-1}$ may be fatal.

The Steenbras River is typical of the acid black water streams common to the Western Cape, and flows into the Steenbras dam which is a major source of potable water for the Cape Town residential area. The water, being of the acid moorland type, is highly coloured due to staining by humic substances and is purified at the Steenbras Water Treatment Plant which uses aluminium sulphate (alum) and other sulphates to coagulate the fine particulate humic substances which then precipitate as a sludge in settling tanks. The sludge is subsequently discharged into a natural stream, which is diverted into a pipe below the Faure Marine Drive, and then flows onto the sea surface in a small cove about 1km south-west of Gordon's Bay harbour. Discharge takes place at night (discharge volumes are between 1600 - 2200m^3 d^{-1}) in order to reduce the aesthetic impact of the brown coloured plume by achieving maximum dilution and dispersal before daybreak. The sludge contains aluminium, which is known to be toxic to plants, invertebrates, fish and higher vertebrates (Birchall, 1990), as well as plant tannins, which may also be toxic. Since the discharge of this sludge has been taking place for many years, concern as to its effects on the marine environment gave rise to the present investigation which formed part of a CSIR contract report (see EMATEK, 1991). The immediate objective of this study was to determine the effect that the alum loaded sludge has had on the subtidal marine environment in the vicinity of the outfall near Gordon's Bay.

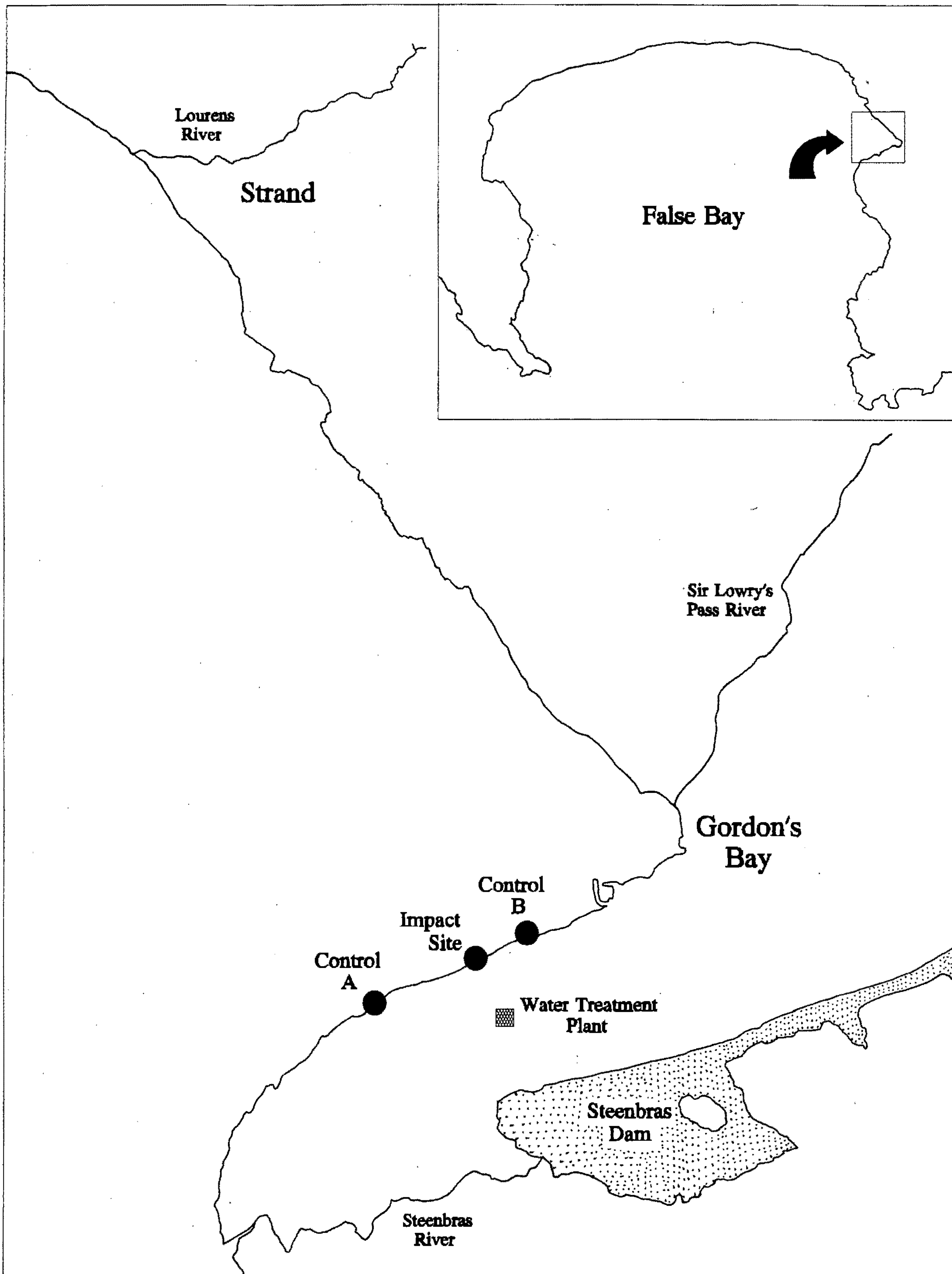

Fig. 3.1: Location of Study Sites in False Bay

STUDY SITES

The Steenbras Water Treatment Plant is situated at an elevation of 288m above sea-level on the slopes of the Hottentots Hólland range of mountains above Gordon's Bay on the eastern side of False Bay. Three sites were selected for subtidal investigations: the impact site in the immediate vicinity of the outfall (the outfall pipe is mounted on the rocks and discharges approximately 2m above the high water mark), about 1km south-west of Gordon's Bay harbour; control A about 1km further south along the coast from the impact site; and control B 500m north of the impact site (see Fig. 4.1). The bottom topography of the three sites is similar and consists of enormous boulders and large cobbles with small pockets of sand. The seabed slopes gently attaining a depth of only 6 - 8m some 100m offshore where the granite formations gradually dip below the sand.

METHODS

In order to compare the variety and abundance of the subtidal fauna at the impact site with that found in the adjacent control sites, two depths were sampled at each site: a nearshore site (4m depth) about 20m from the shore (it was difficult to sample efficiently in water shallower than 2m depth owing to a strong surge along this stretch of coastline); and an offshore site (6m depth) about 80m offshore where the rocky substratum gradually gives way to sand. Two methods were employed at each depth:

i) <u>Synoptic line transects.</u>

At each depth all animals (large enough to be clearly visible underwater) lying within 1m either side of a 25m weighted transect line parallel to the shore were counted by a diver using SCUBA, giving a total survey area of $50m^2$ at each depth. This included counts on horizontal and sloping surfaces and overhangs.

ii) $0.25m^2$ quadrats.

At each of the three sites all benthic organisms were sampled from four randomly placed $0.25m^2$ quadrats at both a nearshore and an offshore depth. All animals were removed and preserved in 4% formalin in sea water for later identification in the laboratory. Where possible organisms were identified down to species level and counted.

The former method gives a general impression of a particular site and is a more accurate representation of larger mobile forms, such as crabs, octopi and lobsters, whereas the latter is more accurate for the smaller more cryptic species such as isopods, amphipods and polychaetes.

iii) Statistical analysis.

A diversity analysis using the coefficient of Jaccard ($C_J = c/ [S_1 + S_2 - c]$, where c = common species to both sites, S_1 and S_2 = number of species present on every site) was performed to compare the three sites and two water depths. The statistic compares the degree of closeness at the various sites with regard to number of species (Figure 4.7).

All sites (both the 4m and 6m depths) were also compared by the Kruskal-Wallis test for dominance and diversity. Forty-seven species were used in this test. This excludes several forms which are either difficult (Balanophyllia) or impractical (Jasus lalandi) to collect (Fig. 4.8).

RESULTS

i) Synoptic transects

The results of subtidal synoptic transects at the three study sites are shown in Tables 3.1, 3.2 and 3.3.

ii) Random Quadrats

Animal species found in random $0.25m^2$ quadrats are listed in Tables 3.4, 3.5 and 3.6.

Table 3.1: Synoptic transect count ($50m^2$) - Impact Site

ORGANISM	INSHORE COUNT - 4m	NUMBER/m^2	OFFSHORE COUNT - 6m	NUMBER/m^2
Porifera:				
Sponge	<1%	0	0	0
Cnidaria:				
Actinia	433	8.66	150	3
Lophogorgia sp	0	0	40	0.8
Mollusca:				
Chiton	3	0.06	0	0
Patella	20	0.04	0	0
Mytilus	3	0.06	0	0
Burnupena	40	0.8	3	0.06
Haliotis spadicea	4	0.08	0	0
Nudibranchs	3	0.06	0	0
Crustacea:				
Plagusia	31	0.62	18	0.36
Jasus Lalandi	0	0	37	0.74
Echinodermata:				
Patiriella	38	0.76	3	0.06
Henricia	1	0.02	1	0.02
Marthasterias	6	0.12	3	0.06
Patiria	4	0.08	3	0.06
Parechinus	193	3.86	37	0.74
Chordata:				
Pyura	10%	0	25%	0
Algae:				
Corallina sp	15%	0	0	0

Note: The percentage count denotes area coverage by the organism.

Table 3.2: **Synoptic transect count (50m²) - Control A**

ORGANISM	INSHORE COUNT - 4m	NUMBER/m²	OFFSHORE COUNT - 6m	NUMBER/m²
Porifera:				
Sponge	2%	0	4%	0
Cnidaria:				
Actinia	17	0.34	3	0.06
Lophogorgia sp	0	0	45	0.09
Bunodosoma	2	0.04	0	0
Mollusca:				
Oxystele	6	0.12	8	0.16
Chiton	4	0.08	0	0
Patella	30	0.06	3	0.06
Mytillus	0	0	0	0
Burnupena	23	0.46	10	0.2
Haliotis midae	0	0	0	0
Haliotis spadicea	0	0	0	0
Nudibranchs	0	0	0	0
Argobuccinum	6	0.12	4	0.08
Marginella	1	0.02	0	0
Phalaium	0	0	1	0.02
Crustacea:				
Plagusia	22	0.44	23	0.46
Jasus lalandi	0	0	53	1.06
Echinodermata:				
Patiriella	71	1.42	0	0
Henricia	2	0.04	1	0.02
Marthasterias	8	0.16	1	0.02
Patiria	3	0.06	2	0.04
Parechinus	715	14.3	5	0.10
Chordata:				
Pyura	4%	0	2%	0
Algae:				
Corallina sp.	0	0	0	0
Pycnogonida:				
Pycnogonid	0	0	1	0.02

Table 3.3: Synoptic transect count ($50m^2$) - Control B

ORGANISM	INSHORE COUNT - 4m	NUMBER/m^2	OFFSHORE COUNT - 6m	NUMBER/m^2
Porifera:				
Sponge	2%	0	1%	0
Cnidaria:				
Bunodosoma	0	0	0	0
Actinia	1	0.02	1	0.02
Lophogorgia sp.	81	1.62	126	2.52
Mollusca:				
Oxystele	4	0.08	2	0.04
Chiton	3	0.04	0	0
Patella	2	0.06	0	0
Mytilus	0	0	0	0
Burnupena	3	0.06	5	0.10
Haliotis midae	0	0	0	0
Haliotis spadicea	0	0	0	0
Nudibranchs	12	0.24	0	0
Argobuccinum	0	0	0	0
Marginella	0	0	0	0
Phalium	0	0	0	0
Crustacea:				
Plagusia	8	0.16	4	0.08
Jasus Lalandi	20	0.40	63	1.26
Echinodermamta:				
Patiriella	20	0.40	6	0.12
Henricia	4	0.08	2	0.04
Marthasterias	12	0.24	3	0.06
Patiria	3	0.06	1	0.02
Parechinus	511	10.22	53	1.06
Chordata:				
Pyura	0	0	0	0
Algae:				
Corallina sp.	0	0	0	0
Pycnogonida:				
Pycnogonid	0	0	0	0
Caphalopoda:				
Octopus	1	0.02	0	0

Table 3.4: Random quadrats (0.25m², 4 replicates) - Impact Site

TAXON	DEPTH - 4m				DEPTH - 6m			
	REPLICATES				REPLICATES			
	1	2	3	4	1	2	3	4
Porifera:								
Polymastia mammillaris					1			
Stelleta sp.								
Tedania scottiae								
Cnidaria:								
Actina equina	1							
Anthostella stephensoni								1
Anthothoë stimpsoni			1				2	
Balanophyllia bonaespei (single coral)								
Lophogorgia flammea								
Wrightella coccinea								
Pocillophora sp.			2					
Pseudactinia flagellifera							4	1
Pseudactinia (varia)	5	7			1			
Bryozooa:								
Alcyonidium nodosum			1					
chaperia sp.								
Sipuncula:								
Golfingia capensis								
Mollusca:								
Burnupena papyracea			1					
Calliostoma (eucosmia)								
Crepidula (aculeata)	1							
Crepidula porcellana	4	1						
Haliotis midae	2							
Ischnochiton textilis								
Lima rotunda								
Oxystele sinensis		1	1					
Patella barbara		2						
Patella miniata		3	2					
Patella tabularis			1					
Polinices didyma		1						

Table 3.4 (Cont.)

TAXON	DEPTH - 4m				DEPTH - 6m			
	REPLICATES				REPLICATES			
	1	2	3	4	1	2	3	4
Crustacea:								
Cryptodromiopsis spongiosa								
Paguristes gamianus					1			
Plagusia chabrus			1		1			
Caprellidae			1					
Temnophilias capensis								
Amphipod type 1		7						
Amphipod type 2					3			
Amphipod type 3								
Amphipod type 4								
Amphipod type 5								
Isopod type 1			1					
Isopod type 2					2			
Isopod type 3								
Polychaeta:								
Diopatra neapolitana								
Euclymene sp.	2							
Euphrosine capensis								
Gunnarea capensis						14		
Harmothoë aequiseta								
Lepidonotus semitectus			4	1	1	4		
Lysidice natalensis			1					
Nereidae		3	11	7	3	8		
Nicolea machrobranchia	2		1		5			
Pherusa sp.								
Piromis arenosus								
Platynereis calodonta								
Echinodermamta:								
Amphiura capensis					2			
Annametra (occidentalis)						1		
Asterina exigua		1	1					3
Henricia ornata			1		1			
Marthasterias glacialis				1				
Parechinus angulosus	6	1	3					
Patiria granifera	1							1
Pentacta doliolum						1	3	1
Thyone aurea								
Chordata:								
Cyona sp.								
Pyura sp.		3		2		9	1	12
Stylea sp.		2		1	1			

Table 3.5: Random quadrats (0.25m², 4 replicates) - Control A

TAXON	DEPTH - 4m				DEPTH - 6m			
	REPLICATES				REPLICATES			
	1	2	3	4	1	2	3	4
Porifera:								
Polymastia mammillaris								
Stelleta sp.		2	1					1
Tedania scottiae								
Cnidaria:								
Actina equina	2			4				
Anthostella stephensoni	6		1	3		1		
Anthothoë stimpsoni								
Balanophyllia bonaespei (single coral)								7
Lophogorgia flammea		1			1		2	1
Wrightella coccinea					1			
Pocillophora sp.			2					
Pseudactinia flagellifera			1					
Pseudactinia (varia)		1						
Bryozooa:								
Alcyonidium nodosum	3	1	1	2	1			
Chaperia sp.					2		1	1
Sipuncula:								
Golfingia capensis					5		1	
Mollusca:								
Burnupena papyracea	3	1	1	2	1			
Calliostoma (eucosmia)			1					
Crepidula (aculeata)								
Crepidula porcellana			1	2				
Haliotis midae								
Ischnochiton textilis			1	1				
Lima rotunda					2			
Oxystele sinensis			6	1				
Patella barbara								
Patella miniata								
Patella tabularis								
Polinices didyma								

Table 3.5 (Cont.)

TAXON	DEPTH - 4m				DEPTH - 6m			
	REPLICATES				REPLICATES			
	1	2	3	4	1	2	3	4
Crustacea:								
Cryptodromiopsis spongiosa					1			
Paguristes gamianus						1		1
Plagusia chabrus							2	
Caprellidae								1
Temnophilias capensis	1							
Amphipod type 1	2							
Amphipod type 2								
Amphipod type 3					37		16	
Amphipod type 4					28		21	4
Amphipod type 5					3			
Isopod type 1								
Isopod type 2								
Isopod type 3					14		5	
Polychaeta:								
Diopatra neapolitana						12	5	
Euclymene sp.								
Euphrosine capensis					3			
Gunnarea capensis					1			
Harmothoë aequiseta					3			
Lepidonotus semitectus	1				10		2	2
Lysidice natalensis					5		1	
Nereidae	5				3			
Nicolea machrobranchia					9		2	
Pherusa sp.	3				1			
Piromis arenosus					1			
Platynereis calodonta								
Echinodermamta:								
Amphiura capensis					7		3	
Annametra (occidentalis)					72		29	11
Asterina exigua	1	1	1	3			1	
Henricia ornata								
Marthasterias glacialis								
Parechinus angulosus	13	22	34	21				
Patiria granifera				1	2		1	
Pentacta doliolum					31			
Thyone aurea					43		14	
Chordata:								
Cyona sp.					1			
Pyura sp.							49	
Stylea sp.								

Table 3.6: Random quadrats (0.25m², 4 replicates) - Control B

TAXON	DEPTH - 4m				DEPTH - 6m			
	REPLICATES 1	2	3	4	REPLICATES 1	2	3	4
Porifera:								
Polymastia mammillaris					1			3
Stelleta sp.								
Tedania scottiae						1		
Cnidaria:								
Actina equina								
Anthostella stephensoni								
Anthothoë stimpsoni								
Balanophyllia bonaespei (single coral)					1		11	
Lophogorgia flammea						2	1	
Wrightella coccinea					1	2		1
Pocillophora sp.								
Pseudactinia flagellifera	1							
Pseudactinia (varia)								
Parerythropodium wilsoni	18	2	8					
Bryozooa:								
Alcyonidium nodosum	3		1	1	4		1	
Chaperia sp.							1	
Sipuncula:								
Golfingia capensis		1			2			2
Mollusca:								
Burnupena papyracea	3		2	1	4		1	
Calliostoma (eucosmia)								
Crepidula (aculeata)								
Crepidula porcellana	3			1				
Haliotis midae								
Ischnochiton textilis								
Lima rotunda								
Oxystele sinensis	2		3	1	1			
Patella barbara								
Patella miniata			1					
Patella tabularis								
Polinices didyma								

Table 3.6 (Cont.)

TAXON	DEPTH - 4m				DEPTH - 6m			
	REPLICATES				REPLICATES			
	1	2	3	4	1	2	3	4
Crustacea:								
Cryptodromiopsis spongiosa								
Paguristes gamianus					1			
Plagusia chabrus								1
Caprellidae								
Temnophilias capensis								
Amphipod type 1								
Amphipod type 2								
Amphipod type 3								
Amphipod type 4								
Amphipod type 5								
Isopod type 1								
Isopod type 2								
Isopod type 3								
Polychaeta:								
Diopatra neapolitana								
Euclymene sp.								
Euphrosine capensis								
Gunnarea capensis					9			
Harmothoë aequiseta								
Lepidonotus semitectus					2			
Lysidice natalensis								
Nereidae								
Nicolea machrobranchia					6			
Pherusa sp.								
Piromis arenosus								
Platynereis calodonta								
Echinodermamta:								
Amphiura capensis					3			
Annametra (occidentalis)					14	1		
Asterina exigua	6	4	6	6	12			4
Henricia ornata	1				2	1		
Marthasterias glacialis		2	3					
Parechinus angulosus	18	11	3	17	9		11	9
Patiria granifera				1			1	
Pentacta doliolum								
Thyone aurea								
Chordata:								
Cyona sp.								
Pyura sp.		1						
Stylea sp.								

In the immediate vicinity of the outfall site there was very little marine life, but further out, sea anemones and red bait (Pyura) became dominant forms. The virtual absence of mussels and subtidal leafy algae at all sites was striking, although the pink, encrusting Lithothamnion covered an appreciable percentage of the rock surfaces and some short tufts of corallines were present (the fragile and brittle nature of organisms such as single corals [Bacanophyllia], small anemones and corallines leads to difficulties when counting and therefore some figures are approximate). Sea urchins (Parechinus) were poorly represented at the impact site compared to controls A and B. Control A had the highest density of sea urchins, while anemones and red bait were sparse. Control B lacked red bait and anemones, but sea fans (Lophogorgia) were common. All three sites had numerous sea fans at depths in excess of six metres. A straight count lumping the shallow and deep levels of each site gave 46 species for control A, 38 for the impact site and 28 for control B. Only six species showed appreciable differences in abundance, when comparing the three sites (see table 3.7).

Table 3.7: Site specific variations in abundance.

SPECIES	ABUNDANCE AT SPECIFIED SITE BUT NOT AT OTHER SITES
Wrightella coccinea	Control B - 6m
Pareythropodium wilsoni	Control B - 4m
Patella miniata	Impact - 4m
Annametra occidentalis	Control A - 6m
Parechinus angulosus	Control A & B - 4m
Pentacta doliolum	Control A - 6m

While the impact site had an abundance of various sea anemones (sessile predators), control A showed an abundance of sea urchins (grazers). This site, lying much further to the east, is less likely to suffer salinity changes than the other two. Control B was populated by more soft corals (micro predators) and the sand bottom had dense populations of sessile polychaetes *(Diopatra neapolitana).*

iii) Statistical analysis.

Jaccard's similarity coefficient, a non-numeric test, indicates that the impact site and control B differ from control A for the shallow four metre contour, although the difference is rather insignificant. The differences between sites for the six metre depth contour are also not significant (see Fig. 3.2).

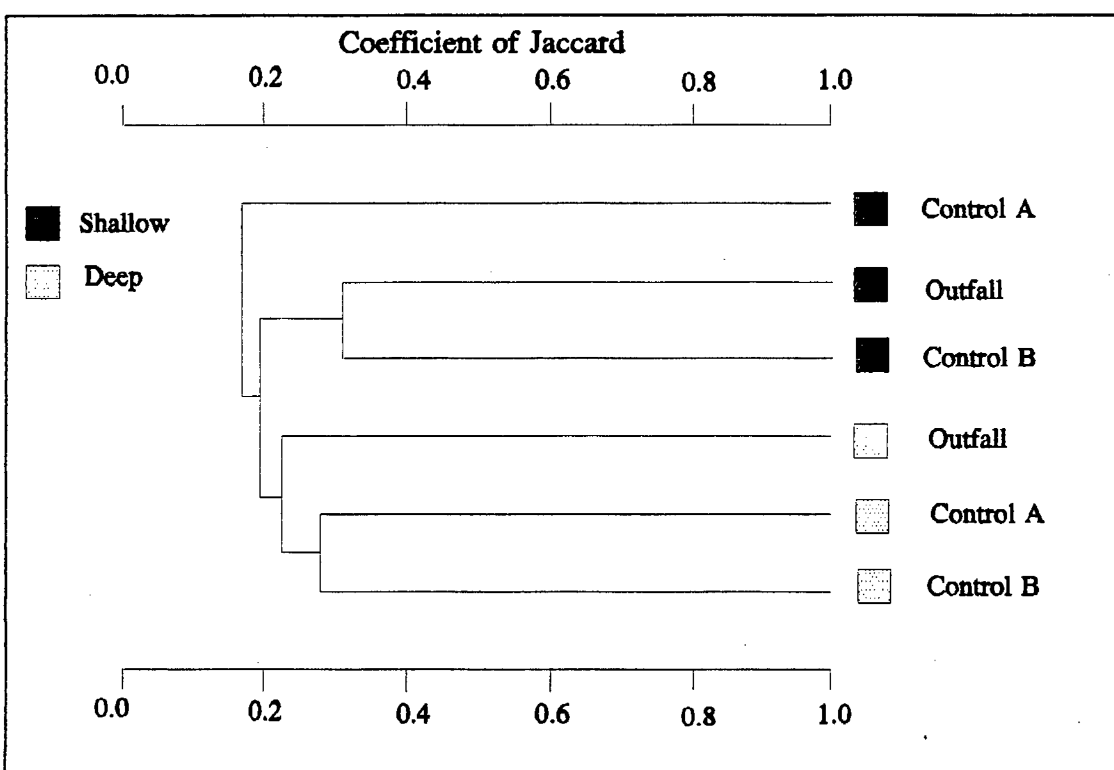

Fig. 3.2: Diversity Analysis using coefficient of Jaccard (after EMATEK, 1991)

The Kruskal-Wallis test confirms the previous test and overall impression that differences are small. Only the shallow level of the outfall site differs significantly from the rest by having a higher diversity and lower dominance (see Fig. 4.3).

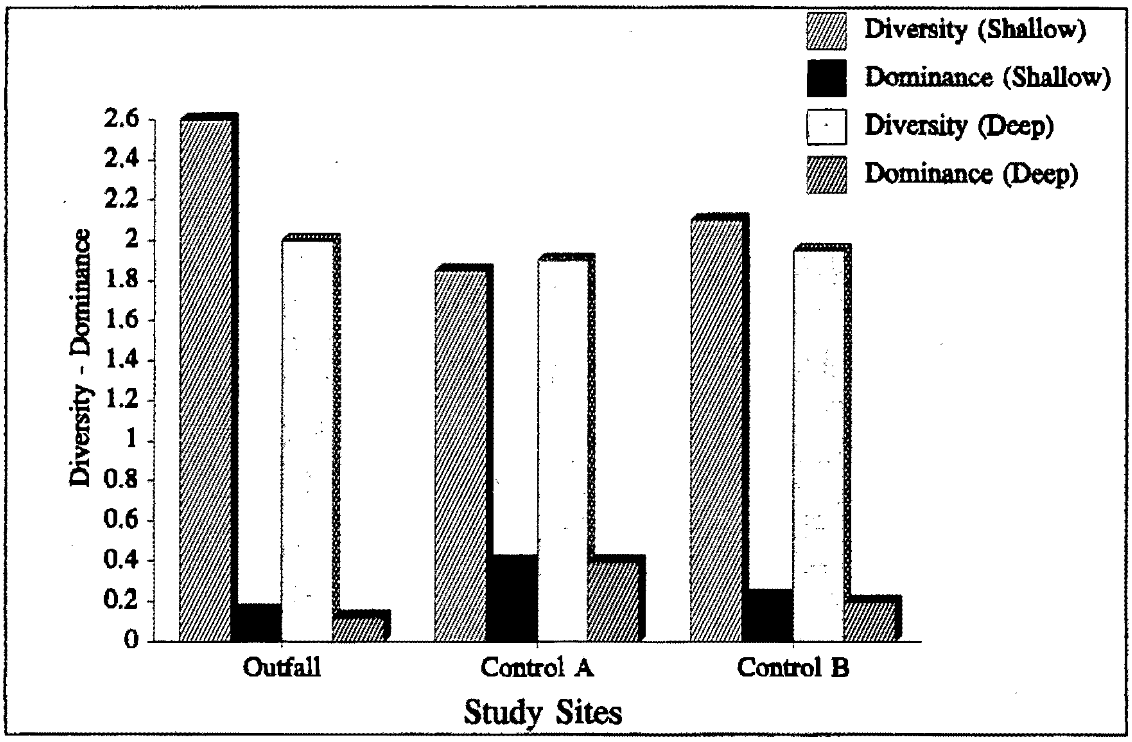

Fig. 3.3: Community Diversity of Benthos at the three study sites (after EMATEK, 1991)

iv) <u>Visibility</u>

On a calm day (light south-easterly wind conditions and a light southerly swell) following sludge release the previous night, underwater visibility was checked at all three sites. Control A showed markedly clearer water (horizontal visibility > 4m) compared to both the impact site and control B (visibility 2 - 3m).

DISCUSSION

Subtidally, the sea bottom at all three sites seemed impoverished when compared with the diversity and abundance seen on the western False Bay coast. The absence of the varied understorey of green and red algae and mussels, seen for example at Miller's Point, was pronounced. However the generally depauperate nature of the fauna in this area is more likely due to hydrological differences rather than the impact of aluminium sludge. Zoutendyk & Bickerton (1990) report the entire stretch of coast between the Strand and Gordon's Bay as having a depauperate intertidal fauna, with the kelps (Laminaria and Ecklonia) being absent because of the somewhat higher mean water temperature on the eastern side of the bay. The general turbidity of the water in this area and the accompanying loss of light with depth would certainly also contribute to a decrease in algae. Morgans (1959) suggests that turbulence also affects the presence or absence and the abundance of species. A broken coastline, which increases wave action at exposed places, causes certain species to flourish there while others flourish in sheltered places. He attributed the decreased abundance and elimination of many species at Gordon's Bay harbour to the lack of turbulence which in turn leads to the deposition of silt from the dirty water and its consequent effect on the biota. It is considered that the general turbidity of the near shore water and frequently lowered salinities associated with the fresh water stream, especially in winter, are chiefly to blame for the impoverished situation. Both effects are completely natural phenomena and are not linked to pollution. The effects of freshwater input on marine biota has been well documented from many parts of the world, including South Africa (e.g. Brown 1983) and the pattern of impoverishment observed at the discharge site is consistent with this view. In this respect, it may be noted that while the discharge of sludge is intermittent, the input of fresh water is continuous, though variable, allowing no respite to the flora and fauna. Watling (1981) found that low salinity depressed the filtering rates of four species of molluscs (Crassostrea gigas, Crassostrea margaritacea, Perna perna, Choromytilus meridionalis) and Cole and Hepper (1954) found that this effect was lessened if the animals were frequently and regularly exposed to conditions of reduced salinity. Davenport (1977) reports an apparent decrease in the toxicity of copper at low salinities for Mytilus edulis and attributes this to the fact that the animal closed its shell during periods of low salinity, thus avoiding the copper. It would therefore seem likely that mussels can avoid aluminium toxicity in the same manner. Goldberg et al. (1978) report that marine organisms from metal contaminated environments are capable of accumulating very high levels of metals in their tissues with no obvious biological effects, and Jenkins et al. (1982) found that the sea urchin Strongylocentrotus purpuratus adapted to increased levels of trace metals and were not stressed over a range of metal concentrations. These results suggest that there may well be a local adaptation by the benthic fauna to higher aluminium concentrations in the immediate area of the outfall.

In general, it can be said therefore that all three sites have very similar biotic characteristics, with the effect close to the outfall merging within some twenty metres from the shore into the generally impoverished benthos found along the east coast of False Bay. It would appear, therefore, that the outlet is perhaps only one of many subtle impact sources contributing to the present situation.

CONCLUSIONS

It is important that patterns of difference must be correlated with concentrations of pollutants and not some other environmental variables. The general turbidity and lower salinity characteristic of the eastern False Bay coast seem to be the chief causes for the impoverished benthic diversity near the sludge outlet, and make it difficult to assess the impact of the aluminium content of the discharge from the Steenbras Water Treatment Plant. However the stress on the benthos in the outfall area is likely to be more severe than that on the other pelagic species (Gabric, 1986), and hence the siting of any steady effluent discharge in the coastal zone needs to consider the impact on biota in the vicinity together with the objective of rapid vertical mixing.

ACKNOWLEDGEMENTS

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CHAPTER FOUR

A COMPARISON BETWEEN THE EFFECTS OF ALUM SLUDGE AND FERRIC SLUDGE ON ROCKY SHORE BIVALVE MOLLUSCS

INTRODUCTION

The rapid physiological and behavioural changes or reactions of bivalve molluscs make them potentially suitable for a quick response in the biological monitoring of pollution in the aquatic environment. Their wide distribution and abundance in temperate and subtropical zones, all year around availability and sedentary habits also contribute to making bivalves, especially mussels, the most useful of marine indicator organisms. Marine mussels (e.g. Mytilus edulis) have been widely adopted in chemical monitoring and surveillance programmes (Goldberg et al., 1978), and Phillips (1977) has reviewed the advantages of using mussels as pollution monitoring organisms. Watling & Watling (1976) used Choromytilus meridionalis in the study of trace metals and the valve movement response of the mussel Mytilus edulis has been used as a tool in biological monitoring (Kramer et al., 1989). Grace & Gainey (1987) report a decrease in the heart and filtration rates of Mytilus edulis after exposure to dissolved copper and Brown & Kumar (1990) found raised iron concentrations in the tissues of the tropical bivalves Saccostrea cullata and Isognomon isognomon due to an iron effluent discharge, and suggest that they have potential as indicators of environmental iron concentrations. Although the effects of these metals and mussel responses to them are well documented, there is scant information on the effects of aluminium in the marine environment, and Pantin (1982) in an extensive review of the effects of pollutants in the sea, including metals, fails to even mention aluminium. The Steenbras Water Treatment Plant discharges an alum (aluminium sulphate) loaded sludge into the waters of False Bay and concern as to the effects of this discharge on the marine environment gave rise to the present study which formed part of a CSIR contract report (see EMATEK, 1991). The study, due to the limited time available was carried out by two scientists, the present author and a fellow scientist, Mr. Steve Webb. The immediate objective of this study was to compare the possible toxic effects of alum sludge and ferric sludge on three species of marine mussels, *Choromytilus meridionalis*, *Mytilus galloprovincialis* and *Perna perna*.

METHODS

Collection Sites

Three species of bivalve mollluscs were collected at the sites listed below:

Species	Collection Site
Choromytilus meridionalis	Blouberg (Atlantic)
Mytilus galloprovincialis	Blouberg (Atlantic)
Perna perna	Dido Valley (False Bay)

Although all the above species are found in the vicinity of the Steenbras outfall, samples were collected from the above areas since they are not subject to any form of aluminium pollution.

Experimental Acclimatisation

The mussels were acclimatised in the laboratory for two weeks in flow-through aquaria with a normal day/night regime. Water temperature was kept constant at 15°C and the salinity at between 34 and 35 ppt.

Size Distribution

The shell length of each mussel was measured before use and mean sample sizes calculated.

Sludge Analysis

The sludge samples were provided by the Scientific Services Branch of the City Engineers Department, with the alum sludge coming directly from the Steenbras Water Treatment Plant. Both alum and ferric sludges were analysed for solid content. Three 100ml beakers of each sludge were evaporated to dryness and mean values for each sample calculated. The sludge samples were refrigerated except when sub-samples were taken for experimental purposes.

Gill Ciliary Transport

The experimental method was based on that of Davenport & Fletcher (1978). An animal was removed from the aquarium and transferred to a small container with sea water of the same temperature and salinity. A scalpel was used to cut anterior and posterior adductor muscles, the shell valve was removed and the mantle excised to expose the gill. Whenever the animal was subjected to a new solution, one minute was allowed to elapse before any reading was taken, so as to permit diffusion into the gill. A light microscope with a calibrated eye-piece was used for determining the speed of carmine particle transport across the gill, a method of estimating ciliary activity first used by Gray (1923). The carmine particles were carefully applied to the gills and allowed to settle, after which extremely consistent rates of transport could be measured. A Cronus Single Event (1/100s) stop watch was used to time the movement of particles across five units of the eye-piece, ensuring that similar size particles and the same specific section of the gill was used each time. Five mussels were treated with increasing concentrations of alum sludge and a further five treated with increasing concentrations of ferric sludge, and a sea water control was set up to measure particle speed at 40 minute intervals for the duration of an individual sludge test. All experiments were performed at a constant temperature of 15°C to avoid changes in metabolic rates caused by oscillating temperatures.

Shell Gaping Frequency and the Production of Pseudofaeces.

Shell gaping frequency and the production of pseudofaeces was examined in Choromytilus meridionalis. Three groups, each of ten similarly-sized mussels, were used in the experiments. One group was placed in 5 litres of alum sludge of known concentration, one in 5 litres of diluted ferric sludge and one in a fresh sea water control. The alum and ferric sludge solutions were changed every 30 minutes, being replaced with solutions having a higher concentration, and fresh sea water replaced the old in the sea water control. The test animals were also initially subjected to pure sea water (i.e. initial concentration of sludge = 0). The water was not aerated during the experiment. Immediately prior to changing the solution, the animals were examined for gaping and the production of pseudofaeces. At the end of the experiment, the animals were returned to aquaria with running sea water and observed at intervals over a period of 7 days, after which they were dissected with a view to discovering any lasting toxic effects of the sludge.

Clogging and Toxicity

Clogging of the gills and associated toxic effects were examined. Three 10 litre tanks (control, alum and ferric) were set up, each holding individuals of Perna, Choromytilus and Mytilus. On the first and third days, sludge concentration in tanks 1 (alum) and 2 (ferric) were made up to 50 ppt in fresh sea water and the sea water in tank 3 (control) was replenished. On days 2, 4 and 5 half a litre of the solution was drawn off and replaced by half a litre of alum or ferric sludge in tanks 1 and 2 respectively; in the control tank it was replaced by half strength sea water. Gill clogging, gill abnormalities, gut contents and sludge in the mantle cavity were investigated after the fifth day.

RESULTS

Sludge Analysis

The alum sludge was found to contain 0.473% solids and the ferric sludge 0.238% solids.

Gill Ciliary Transport

The results of gill ciliary transport in individual mussels treated with alum and ferric sludges are shown in Figures 4.1 (a-e) and 4.2 (a-e) respectively. Control animals (with a mean overall particle speed of 0.385mm. sec-1) displayed virtually constant gill ciliary activity, and hence rate of transport, over the three hour period for which they were observed (see Fig. 4.3). This finding is in agreement with the observation of Watkins & Simkiss (1988) that ciliary activity in Mytilus edulis remained virtually unchanged over the course of three hours. The overall means of all the alum tests are displayed in Figure 4.1 (f) and the overall means of the ferric sludge in figure 4.2 (f). Neither the alum sludge nor the ferric sludge has any significant effect on gill transport rates up to concentrations of 100 ppt (100 000ppm). This contrasts markedly with the effect of ammonia on the same preparation (figure 4.4). It may also be noted that decreased salinity impairs ciliary activity (figure 4.5).

Gaping frequency

Results of the gaping frequency experiment conducted on Choromytilus meridionalis are shown below (see Table 4.1). The mean number of control mussels open during the experiment was 9.36 (SD = 0.65). In increasing concentrations of alum sludge the mean number open was 9.18 (SD = 1.64), and in ferric sludge 8.46 (SD = 1.64). Examination after one week showed that all mussels in all solutions had byssus attachments and that closing responses were normal. No sludge was found in the gut or mantle cavity, except for one individual which had been subjected to alum sludge, where a minor sludge stain was observed in the gut. No abnormalities were observed.

Table 4.1: Shell gaping frequency in Choromytilus meriodionalis illustrating the effect of Alum (Al.) and Ferric (Fe.) sludges on shell opening and pseudofaeces production.

TIME (min.)	CONC. (ppt)	NUMBER OPEN			PSEUDOFAECES		
		Ctrl.	Al.	Fe.	Ctrl.	Al.	Fe.
0	0	9	6	9	0	0	0
30	2	9	10	9	0	8	10
60	4	10	9	10	0	9	10
90	6	9	10	5	0	10	10
120	8	10	9	10	0	10	10
150	10	10	10	10	0	10	10
180	12	9	10	9	0	10	10
210	14	9	8	8	0	10	10
240	16	8	9	9	0	10	10
270	18	10	10	6	0	10	10
300	20	10	10	8	0	10	10

Clogging and toxicity

All animals of all species were alive at the end of the experiment and all showed normal fast closure responses, indicating good physiological condition. In the case of Choromytilus, no animal subjected to ferric sludge had sludge in the mantle and only one (of a total of 10) showed small patches of sludge in the gut. In the case of alum sludge, one had sludge in the mantle and four had sludge in the gut. The gills were normal. For Mytilus subjected to ferric sludge, four (out of 10) had sludge in the mantle and four had sludge in the gut, while for alum sludge the totals were six and three respectively. In the case of Perna subjected to ferric sludge, four had sludge in the mantle and eight (out of 10) in the gut. In the alum sludge, seven had sludge in the mantle and eight in the gut.

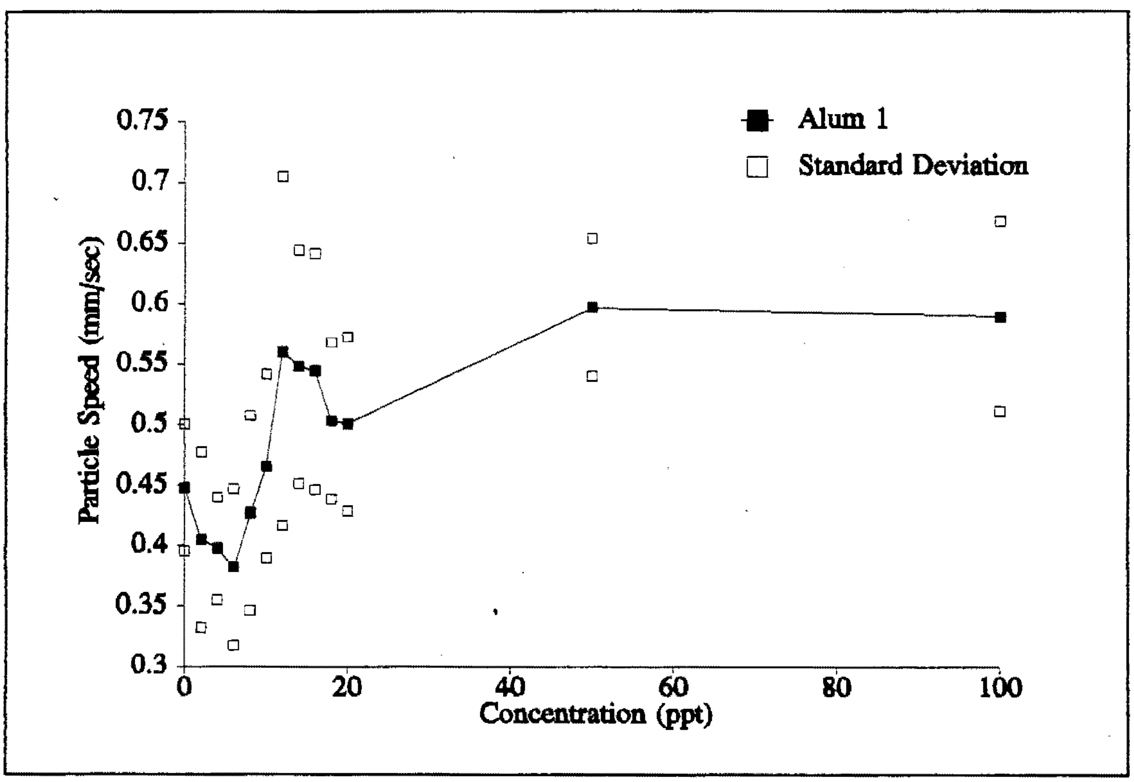

Fig. 4.1a: Mean particle speeds for an individual (A1) alum treated mussel

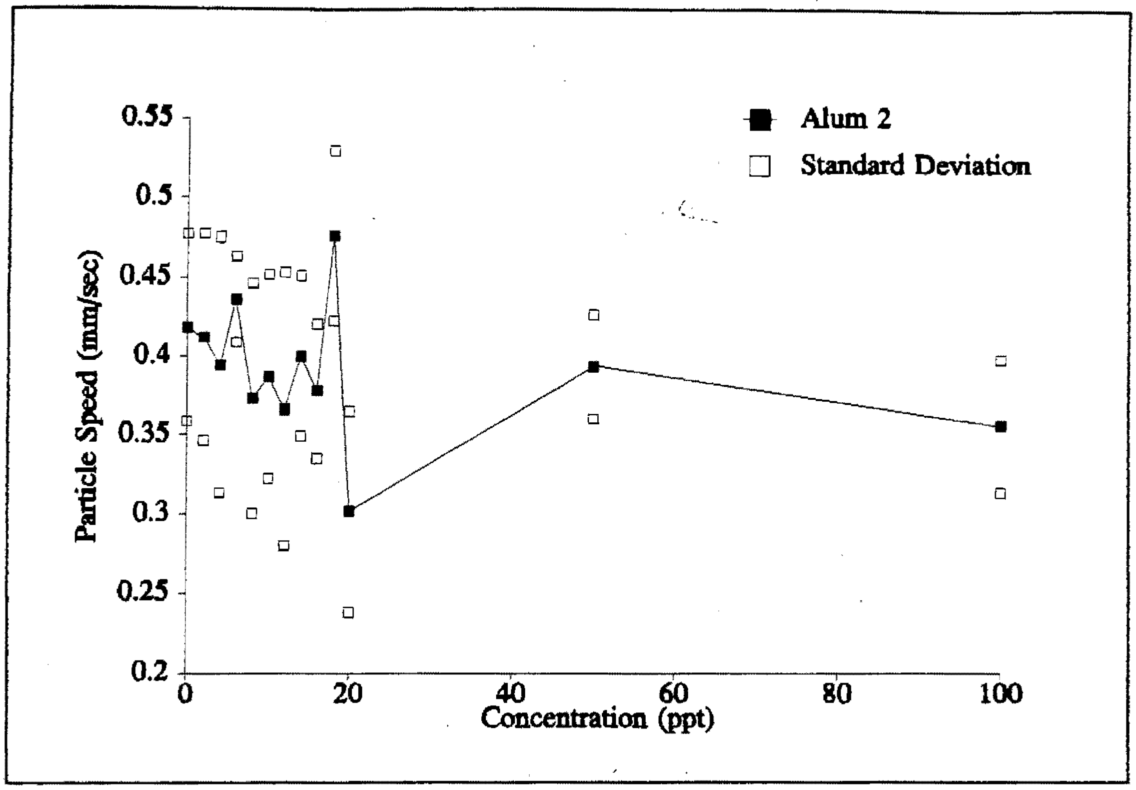

Fig. 4.1b: Mean particle speeds for an individual (A2) alum treated mussel

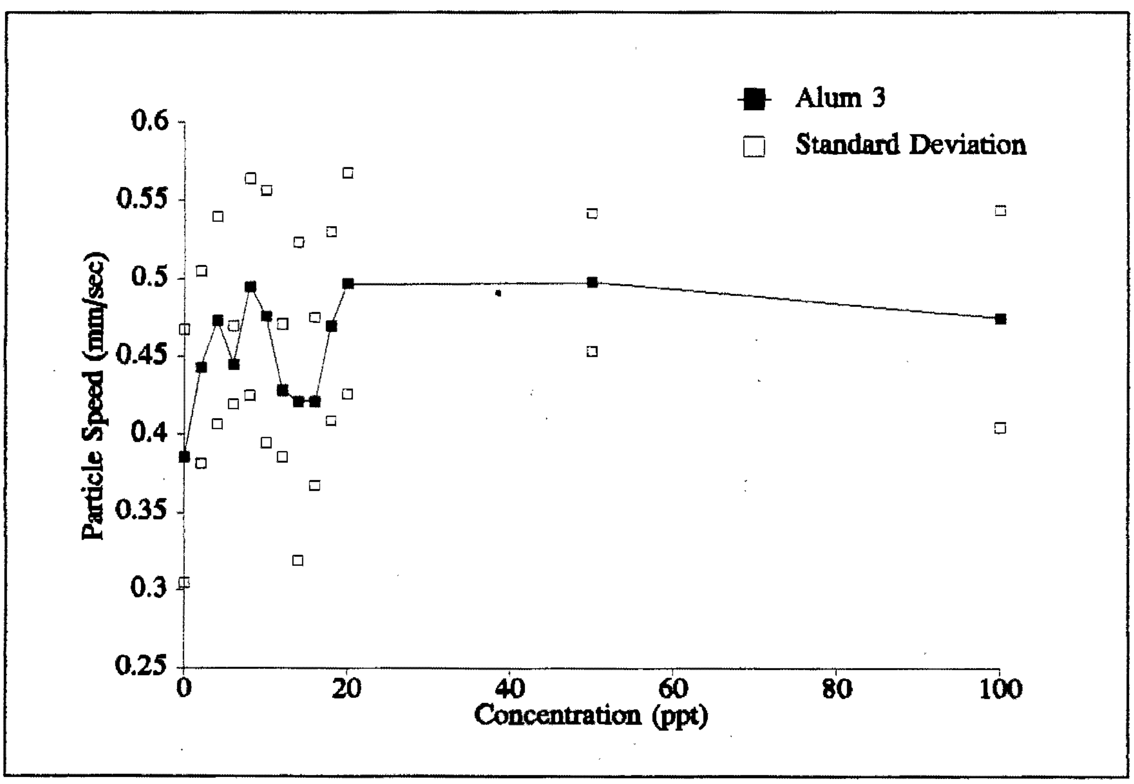

Fig. 4.1c: Mean particle speeds for an individual (A3) alum treated mussel

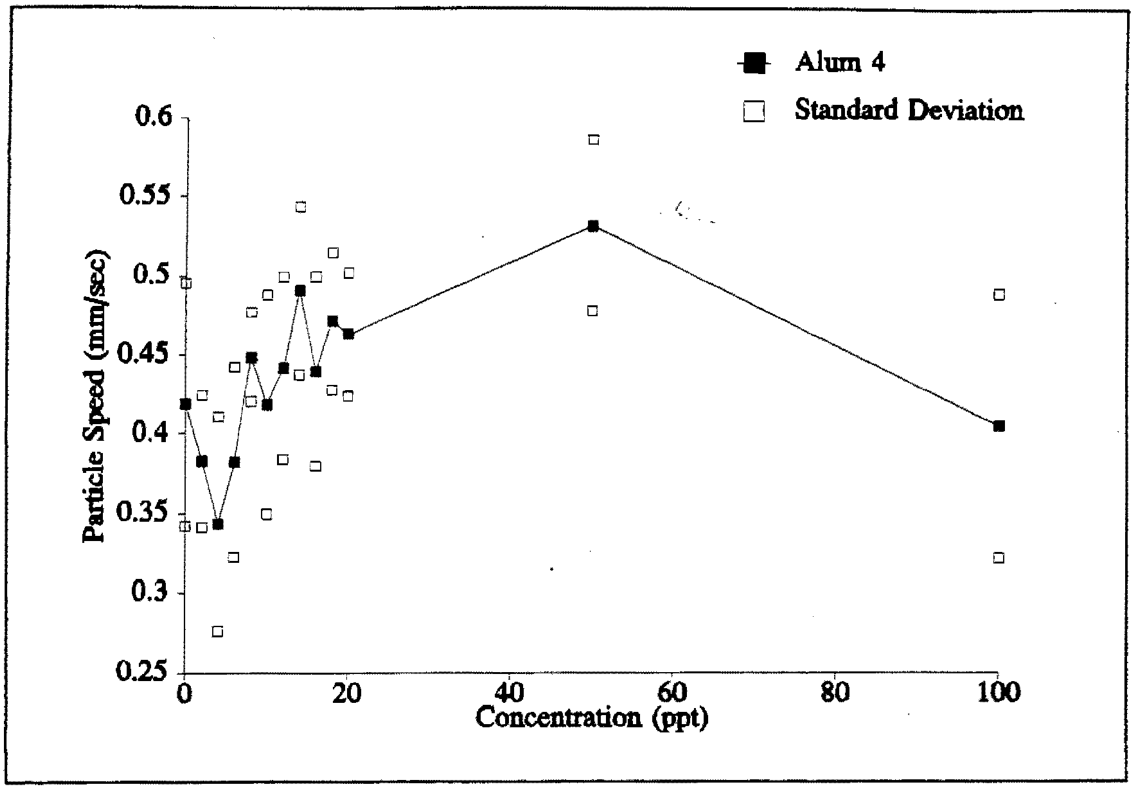

Fig. 4.1d: Mean particle speeds for an individual (A4) alum treated mussel

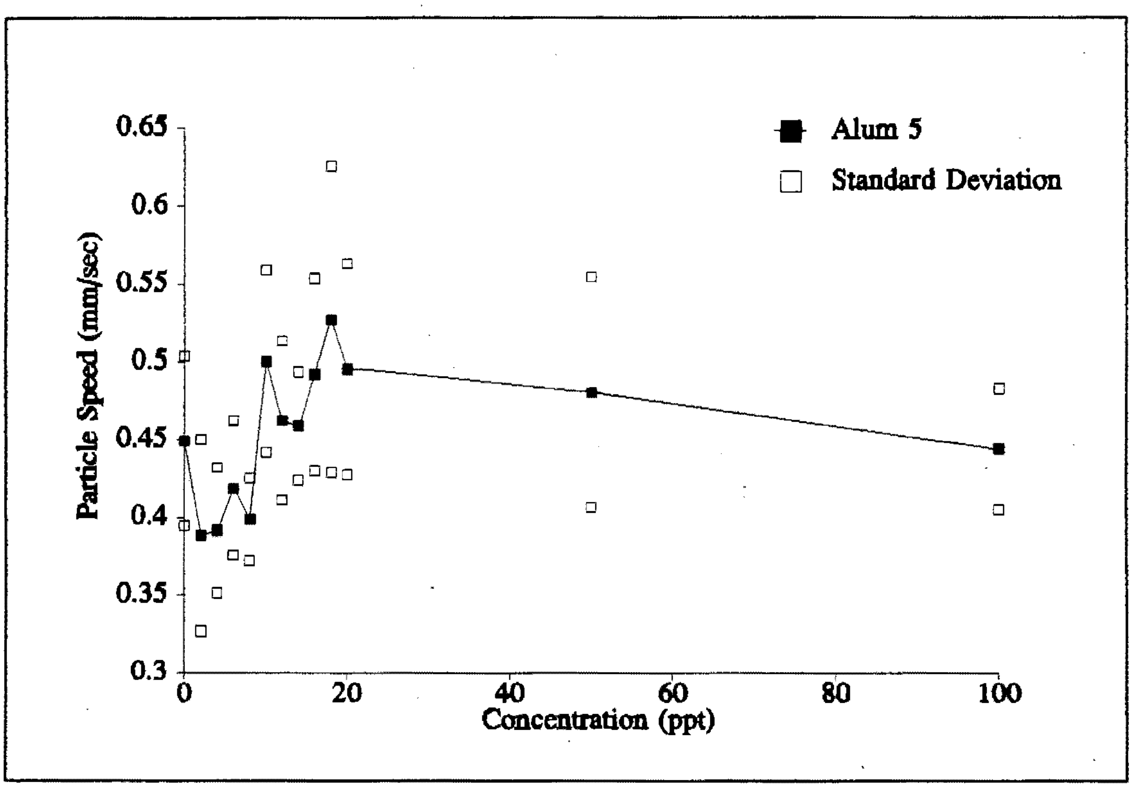

Fig. 4.1e: Mean particle speeds for an individual (A5) alum treated mussel

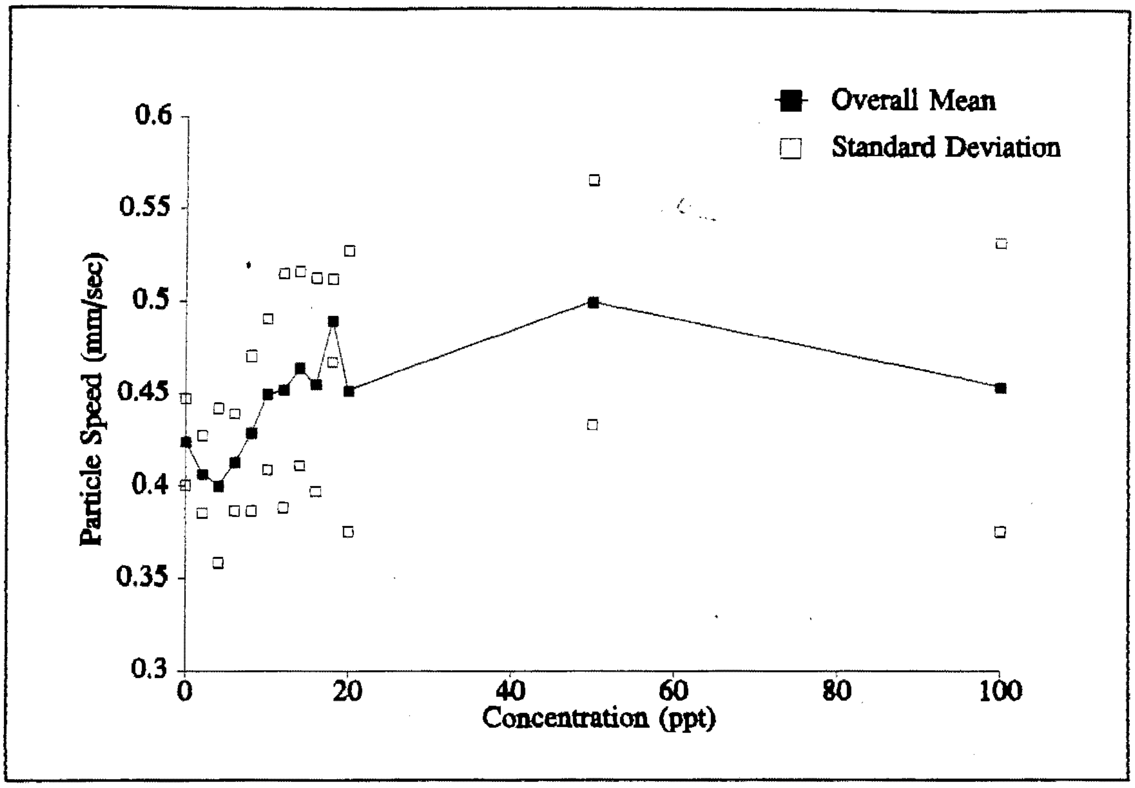

Fig. 4.1f: Overall mean particle speeds for all alum treated mussels

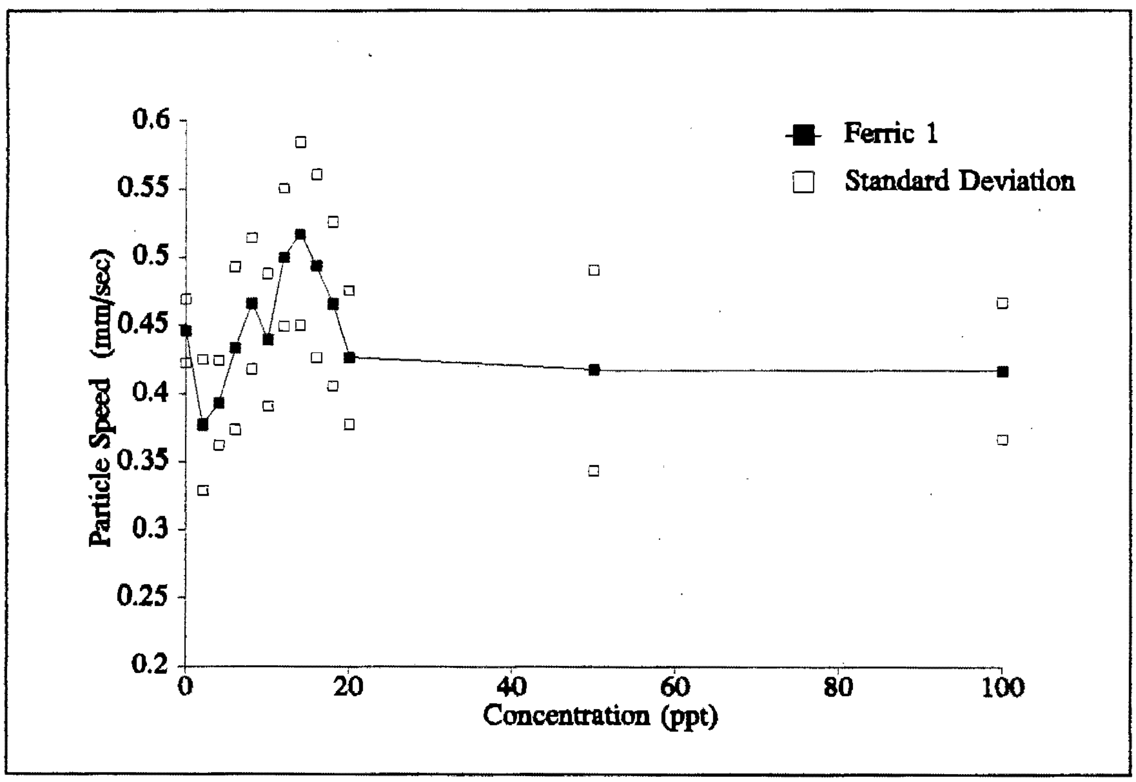

Fig. 4.2a: Mean particle speeds for an individual (F1) ferric treated mussel

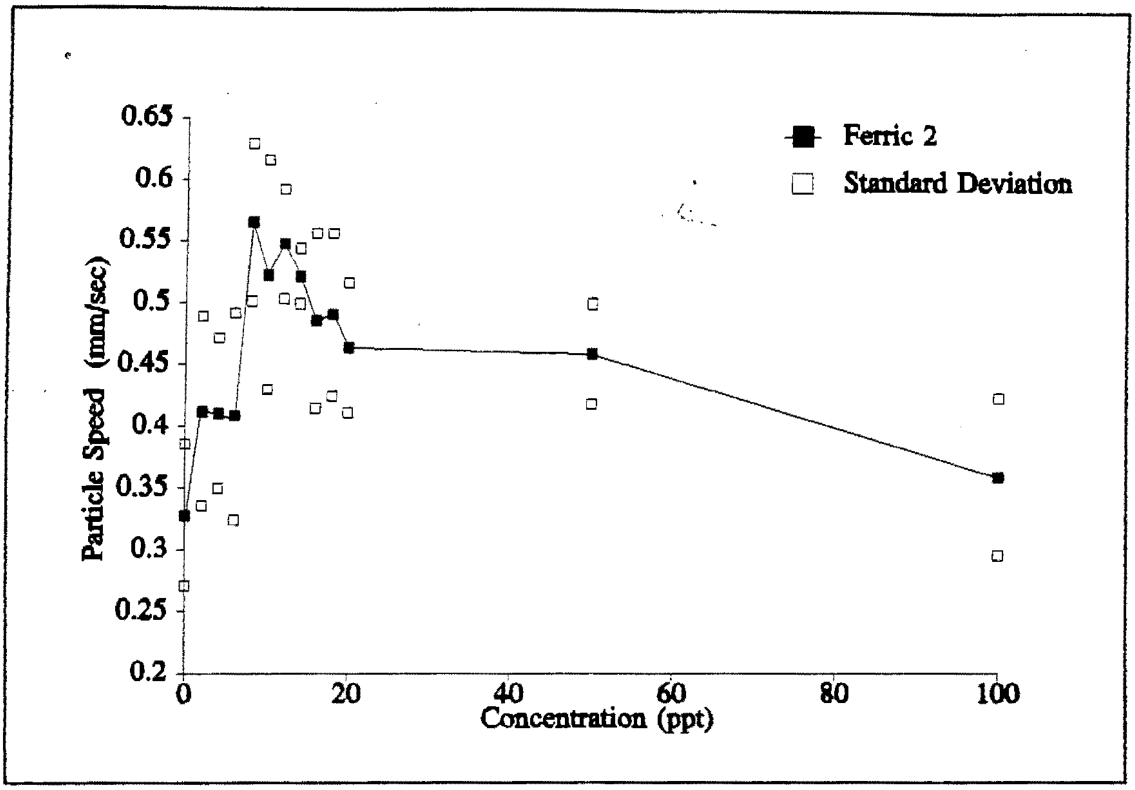

Fig. 4.2b: Mean particle speeds for an individual (F2) ferric treated mussel

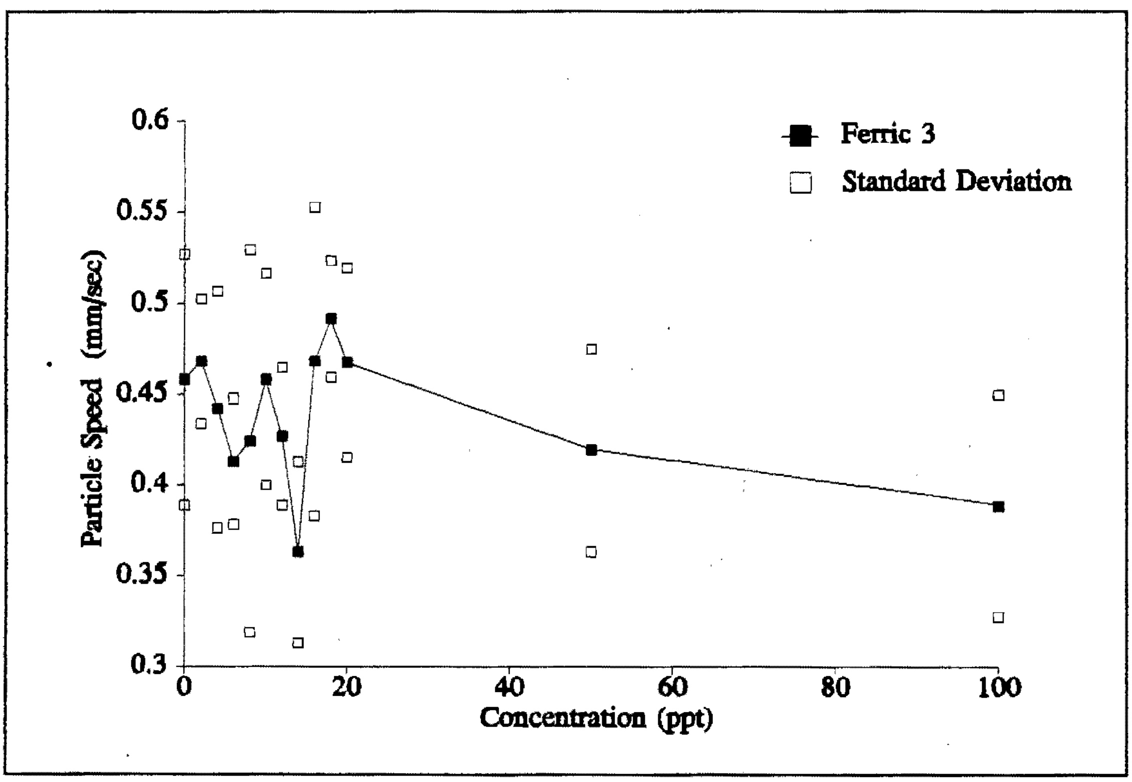

Fig. 4.2c: Mean particle speeds for an individual (F3) ferric treated mussel

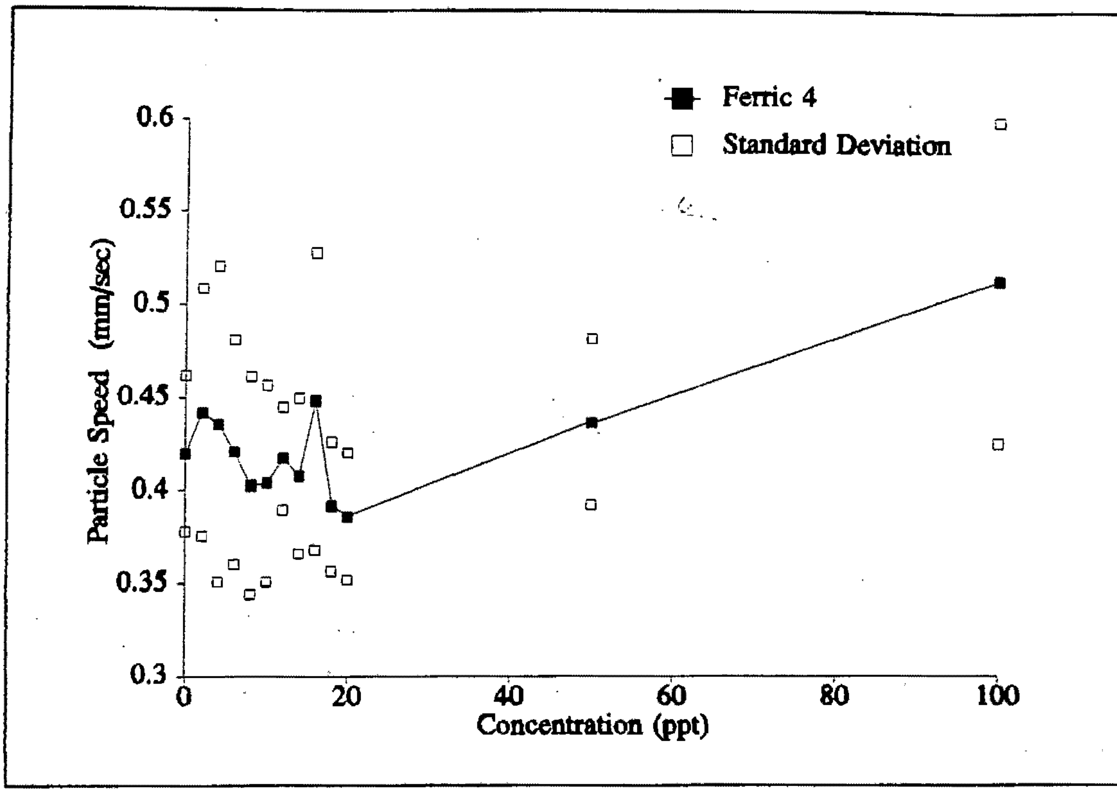

Fig. 4.2d: Mean particle speeds for an individual (F4) ferric treated mussel

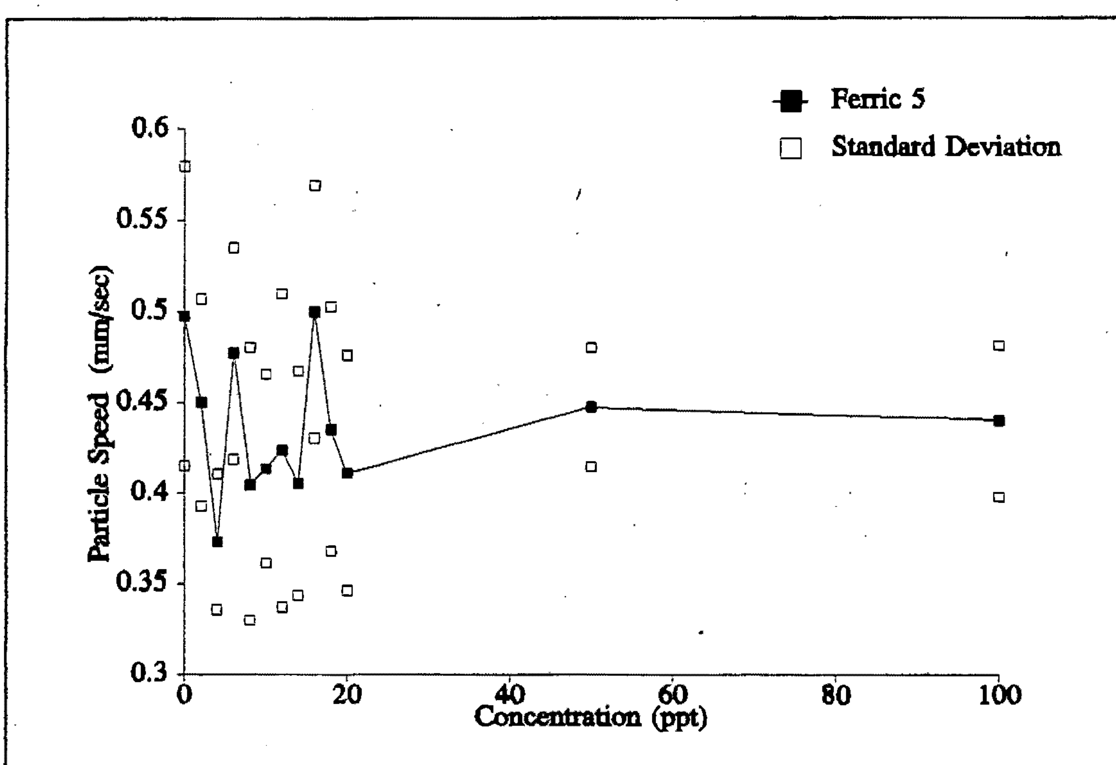

Fig. 4.2e: Mean particle speeds for an individual (F5) ferric treated mussel

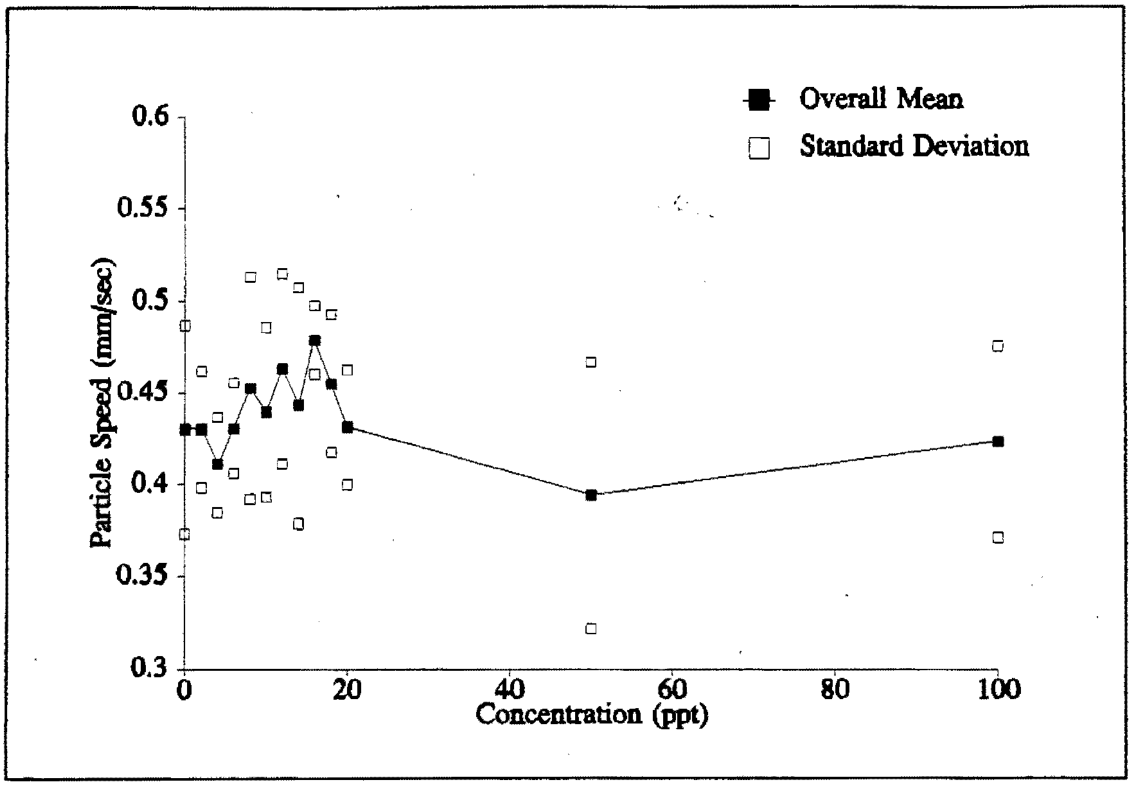

Fig. 4.2f: Overall mean particle speeds for all ferric treated mussels

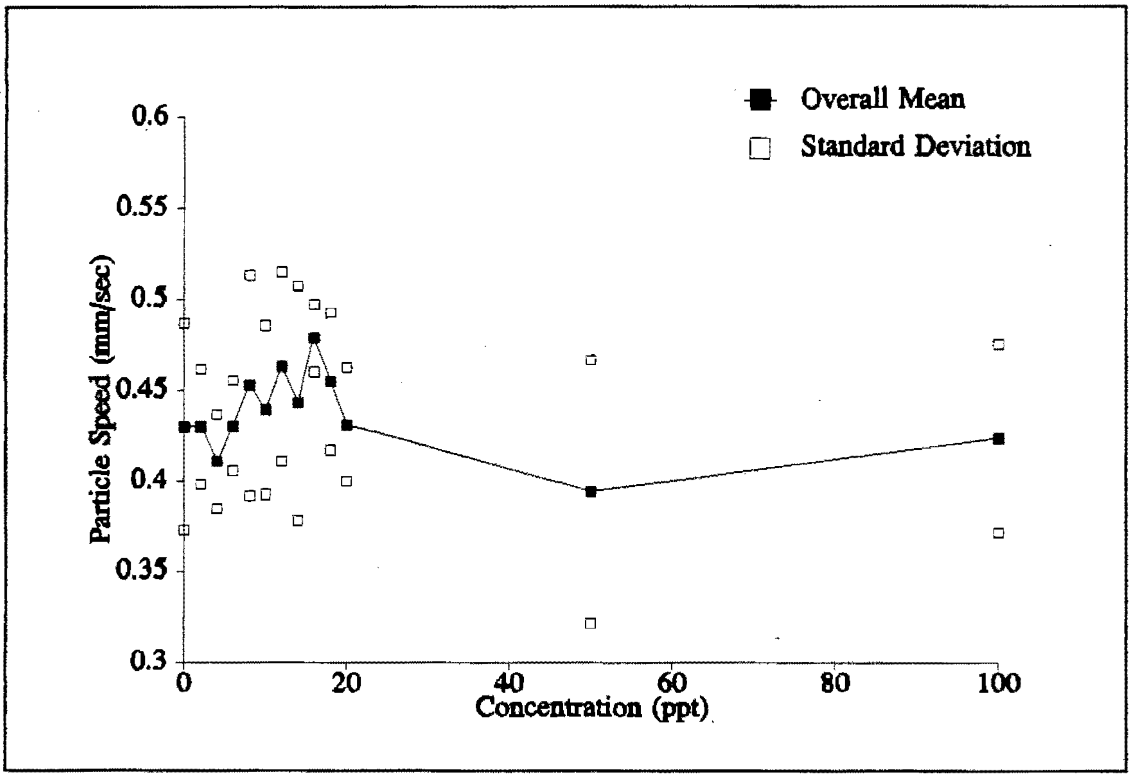

Fig. 4.3: Control showing particle speed variation for duration of experiment

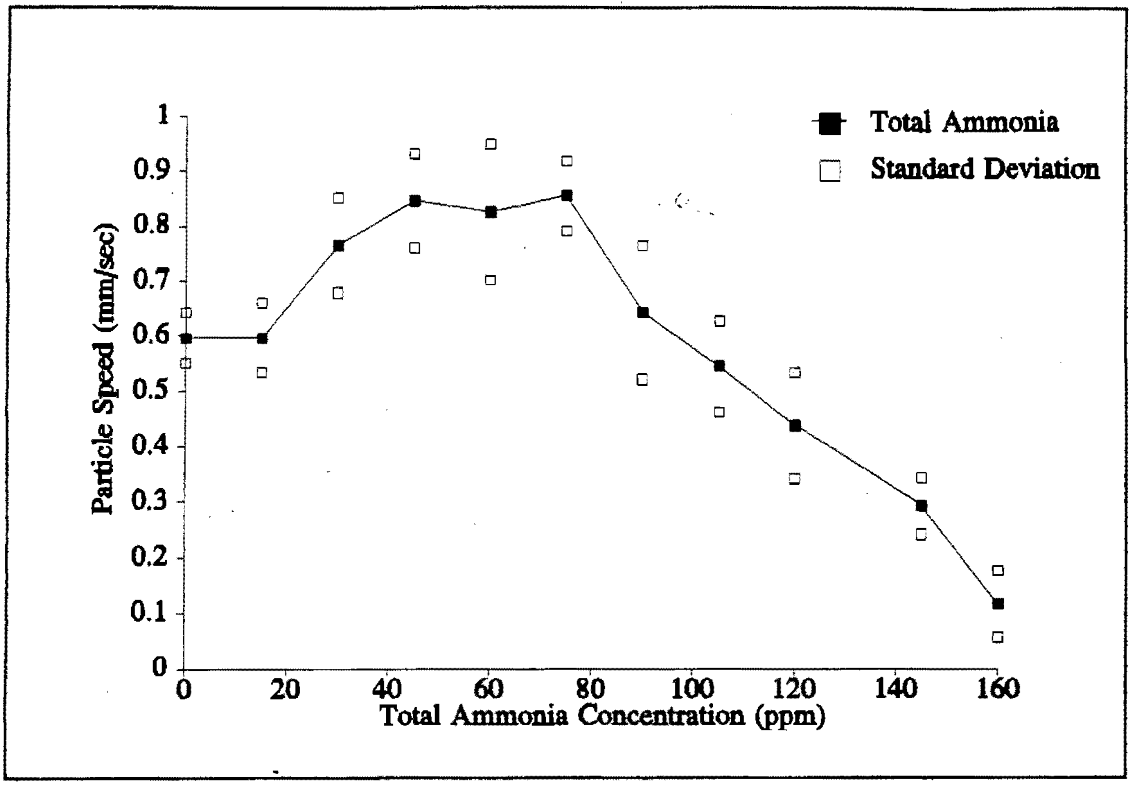

Fig. 4.4: The effect of ammonia on gill cilia activity in <u>C. Meridionalis</u>

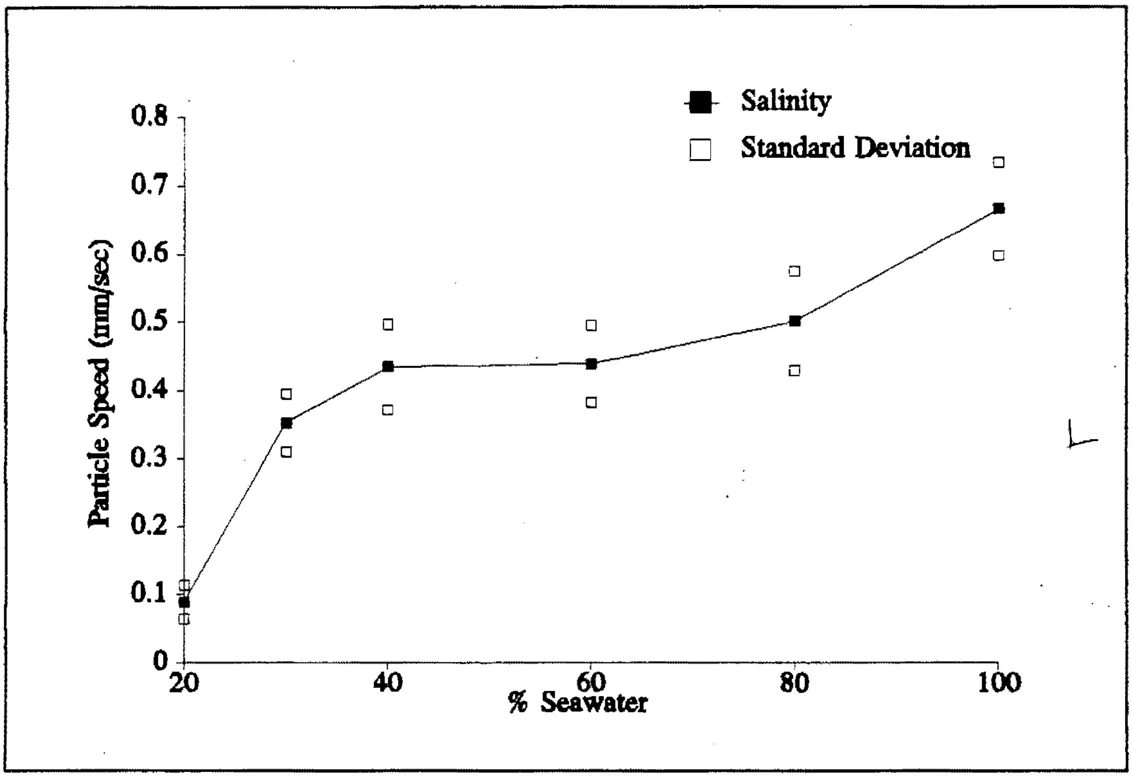

Fig. 4.5: The effect of salinity on gill cilia activity in <u>C. Meridionalis</u>

DISCUSSION

Size is considered important in physiological processes (Taylor & Brand, 1975; Bayne & Livingstone, 1977; Bryan & Uysal, 1978) and Wallis (1975), in experiments on thermal tolerance of Mytilus edulis, reports that size makes a significant difference in the level of resistance as well as tolerance. It has been suggested that metabolic factors which vary with age or size are the causative agents and not the structural properties such as shell size or thickness. Hence in the present study, the similar mean sample sizes allow valid inter-sample comparisons. Increasing concentrations of both alum (Fig. 4.1) and ferric (Fig. 4.2) sludge cause no significant deleterious effect on the gill cilia activity of Choromytilus meridionalis. This is in contrast to the results of Viljoen (1990) who reports the toxic effect of alum sludge on the gill cilia activity of the sandy beach clam Donax serra. Although a real difference between the species is certainly indicated, this effect in Donax may be attributed to a clogging effect which is more an experimental artefice than a natural occurrence since Donax has an elaborate inhalent siphon filter system which may protect the gills when the animal is intact. Newell (1979) reports that varying numbers of particles can influence ciliary activity and thus the initial fluctuations (0-30ppt) in ciliary activity are probably caused by differential stimulation of the cilia (see Figs. 4.1 and 4.2).

The closure of the shell valves in the common mussel Mytilus edulis in the presence of toxic substances has been recorded by Dodgson (1928) and Shapiro (1964), and Manley (1983) reports that partial isolation may reduce the effects of short term low level pollution without incurring any metabolic disadvantages of full isolation. Ammonia caused a drastic reduction of ciliary activity at 160 ppm (see Fig. 4.4) which shows the extreme sensitivity of mussels in the detection of toxicants. Davenport and Manley (1978) report that shell closure is induced at about 0.2 ppm of copper, further indicating this sensitivity. Thus the lack of response to comparatively high concentrations of both alum and ferric sludges clearly indiates their lack of short-term toxicity.

Mussels cannot control their blood concentrations by the active uptake or extrusion of salts as do osmoregulators, such as teleost fish and many crustaceans, but being osmoconformers, they can only exert control over the composition of their internal media by behavioural means (Davenport & Fletcher, 1978). Periodic fluctuations in environmental salinity are tolerated by closing their shell valves and isolating their body tissues from the environment. Choromytilus shows a decline in gill cilia activity with decreasing salinity (see Fig. 4.5), and Newell (1979) reports that Mytilus edulis exhibits a stress response in the form of increased oxygen consumption when exposed to low salinities. When intact, Mytilus isolates itself from low salinity by closing its shell valves and the salinity of water retained in the mantle cavity of closed mussels is never less than about 21 ppt (Milne, 1940; Shumway, 1977; Davenport, 1977). Low sea water concentrations have been reported to have not only a detrimental effect on growth (Davis, 1958; Chanley, 1958; Bayne, 1965; Seed, 1976) but even to be lethal in extreme conditions (Castagna & Chanley, 1973). Almada-Villela (1984) demonstrated poor growth rates in Mytilus edulis in low steady salinity regimes but suggests that acclimation of mussels to extreme low salinites (5-10 ppt) may be achieved if salinities are reduced gradually.

Ameyaw-Akumfi & Naylor (1987) report some evidence of weak circadian rhythms in the shell gaping behaviour of Mytilus edulis (with greater duration of shell closure during hours of expected daylight) and suggest that this behaviour could represent an adaptational defense against visually-feeding predators. However, this behaviour was not noted during the present study. The faster filtering of the ferric sludge, as opposed to alum sludge, is probably due to the higher solid content of the latter, and Davenport & Woolmington (1982) report that even under conditions of intermittent feeding, pumping rates can be maintained.

CONCLUSION

Neither alum nor ferric sludge has any significant short-term sublethal toxic effects on the rocky shore mussels investigated, even at the highest concentrations that could be tested. This conclusion is confirmed by the absence of shell closure, indicating that no danger or irritation was experienced by the mussels exposed to sludge. This would therefore suggest that the fluid component of the sludge has negligible toxicity, for while the mussels can effectively inactivate the solid particles by turning them into pseudofaeces, they have no such defence against toxins in solution other than shell closure. It would seem that the decreased salinities in the immediate region of the outfall (as a result of the fresh water stream input) may have a more deleterious effect than either the alum or ferric sludges. However the presence of all four species, Choromytilus meridionalis, Mytilus galloprovincialis, Perna perna and Aulacomya ater, in the intertidal zone in the immediate vicinity of the outfall suggest that neither the alum sludge nor decreased salinities have a profound impact on any of the mussel species.

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CHAPTER FIVE

SYNOPTIC SURVEY OF SUBTIDAL MACROPLASTIC DEBRIS IN FALSE BAY

INTRODUCTION

There is a growing volume of literature on persistent marine debris in the world's oceans, and plastic items have consistently proved to be the major component of this anthropogenic litter. The occurrence of plastic debris in the marine environment is undoubtedly a global phenomenon as indicated by reports from the North Pacific (Venrick et al., 1973; Yoshida & Baba, 1985; Dahlberg & Day, 1985; Jones & Ferrero, 1985), South Pacific (Gregory et al., 1984), North Atlantic (Dixon & Dixon, 1983; Colton et al, 1974; Carpenter et al., 1972; Carpenter & Smith, 1972), South Atlantic (Morris, 1980a; Ryan, 1988), Meditteranean (Morris, 1980b); remote islands (Ryan & Watkins, 1988; Wilbur, 1987); beaches as diverse as Alaska (Merrell, 1984 & 1985), Java (Willoughby, 1986), Hawaii (Henderson, 1983), New Zealand and Australia (Gregory, 1977, 1978a, b), Antarctica (Gregory, 1984), the U.S.A and Canada (Gregory, 1983; Cundell, 1973), Scotland (Scott, 1972; Bourne, 1977), England (Kartar et al., 1973 & 1976; Morris & Hamilton, 1974), France and Denmark (Dixon & Dixon, 1981), Lebanon (Shiber, 1979), Spain (Shiber, 1982 & 1987) and South Africa (Ryan & Moloney, 1990).

Although initially portrayed as an isolated problem and a solely aesthetic concern, the issue of persistent plastic debris in the marine environment is now perceived as a lethal threat which causes the widespread mortality of many marine animals including seals, seabirds, turtles, fish and crustaceans. The deceptively simple nature of the threat, the perceived abundance of marine life and the size of the oceans, have until recently caused resource managers to overlook or dismiss the proliferation of potentially harmful plastic debris as being insignificant (Laist, 1987).

Plastics at sea can be classified into two major types (Azzarello & Van Vleet, 1987) based on their origins, viz., 'user' and industrial plastics. The former are the most conspicuous and consist of plastic materials directly used by man, e.g. plastic bags, cups, bottles, packaging materials, ropes and nets. The latter are less conspicuous and generally take the form of small spherical or cylindrical compounded plastic disks (< 4mm diam.). They are the industrial bulk material in which plastics are manufactured and transported prior to their transformation into user plastics by remelting and employing additives (Van Franeker, 1985). The commonest plastic materials are polyethylene, polystyrene, polyvinyl chloride and polypropylene. The principle synthetic compounds used in the fishing industry are polyamide (nylon), polyester, polyethylene and polypropylene (Pruter, 1987).

The main problem of plastic debris is its persistence in the marine environment and this is exacerbated by the fact that plastics packaging is designed for a single use, i.e. it is made to be thrown away. Plastics float, are non-biodegradable, and only slowly degrade upon exposure to ultra-violet radiation. Extension of the service life of some plastics has been made possible recently by incorporation of ultra-violet light stabilisers and antioxidants. This has led to a corresponding increase in the persistence of plastics and their inherent problems in the environment (Dixon & Dixon, 1981). Two factors affect the danger posed by synthetic debris - chemical composition and physical configuration. Some of the most desirable properties of synthetic materials e.g. low cost, light weight durability and great strength also make the articles more likely to be discarded, less likely to sink, longer lasting once discarded or lost, harder for marine organisms to escape from once entangled, and less likely to be digested or eliminated once ingested.

The most abundant plastic litter in near-surface waters is polyethylene sheeting, derelict gillnets, trawl-net fragments, strapping and packing bands and plastic bags (FAO, 1987).

The fate of small particles at sea, and the role of microparticles in marine systems remains unresolved (Gregory, 1978b). The small scale distribution pattern of plastic particles at the sea surface is clustered around zones of surface convergence, and large concentrations of floating debris are frequently encountered in discrete convergence lines during calm weather (Bourne & Clarke, 1984). There are three factors which influence the distribution of plastics at sea: their source areas; surface currents and winds; and their lifespan at sea. Firstly, density is inversely related to the distance from major source areas; secondly winds and surface currents are responsible for dispersal away from source areas (low density foamed plastics are probably influenced more by wind than currents, but polyolefin plastics, with densities approaching that of sea water, are probably influenced more by currents than by the wind); thirdly, long lived plastic particles can travel at sea until eventually trapped in 'sinks' such as stable convergent gyres (e.g. Sargasso Sea - Carpenter & Smith, 1972) and beaches where they are stranded (Gregory, 1978a), whereas short lived plastic particles may degrade before reaching 'sink' areas.

Depending on the type of debris, it may float at the surface, be suspended at mid-depths or sink to the sea floor. Ocean currents eventually carry much of the floating debris ashore. Once released into the ocean, floating debris tends to be accumulated by natural processes along lines of convergence and between discrete water masses, at the core of major current gyres, or on beaches. Since the debris is anthropogenic, it tends to be most concentrated around important fishing grounds, well travelled shipping corridors, or major ocean dumping sites. These areas often overlap important habitats for large numbers of seals, seabirds and other marine animals. Thus debris is not distributed randomly at sea but is often concentrated in areas that are of particular importance to marine animals.

Day & Shaw (1987) suggest that many of the small plastic fragments are generated at sea from larger pieces. Small particles collectively present a much larger surface area than do the fewer large pieces of plastic. Hence they are likely to be more important sources of toxic substances (additives such as PCBs, colourants and plasticisers) into the environment through surface leaching. Although it is possible that larger user items gradually degrade to form abundant small particles, provided they remain at sea long enough, the rates of breakdown involved are unknown.

Most plastic debris enters the marine environment along populated ocean coasts due to concentrations of vessel traffic, commercial fishing, industrial effluent, and river-born waste discharges (Dixon & Dixon, 1981), and concentrations of plastic debris are thus likely to be highest close to major shipping lanes and in oceanic convergent zones (Day & Shaw, 1987; Vauk & Schray, 1987; Carr, 1987). Horsman (1982) estimated that 639000 plastic containers, including plastic bags are dumped each day by the world fleet of merchant ships, and Uchida (1985) reported that 21 000km of drift net is used nightly in the north Pacific salmon and squid fisheries alone. Estimates of fishing gear lost and discarded at sea each year could exceed 100 000 tonnes and the impact of this debris on marine life is lethal, as evidenced by the retrieval of 15km of drift net found floating in the central north Pacific with 350 dead seabirds entangled in it (Jones & Ferrero, 1985).

The direct threats of plastic debris to marine life appear to be relatively uncomplicated and mechanical. Animals that become entangled may drown, have the ability to catch food or avoid predators impaired, incur wounds and infections from abrasive or cutting action of debris, or have normal behaviour patterns altered in ways that place them at a survival disadvantage. A greater threat is posed to seabirds by small plastic particles floating at the sea surface. These are ingested by seabirds and fish which may be unable to distinguish between normal prey items and small pieces of floating plastics. The pieces can cause blockage of the intestine or ulceration of the stomach lining. Soft polyethylene plastics may remain in the stomachs of seabirds for two to three months and harder plastics may remain for ten to fifteen months (Day, 1980). It is estimated that up to one million seabirds and approximately 100 000 marine mammals die each year after ingesting or becoming entangled in plastics debris (Wirka, 1988). Off South Africa, most entanglement is caused by either fishing gear (rope, netting and fishing line) or disposable packaging (primarily plastic packing straps and plastic bags) (Ryan, 1989).

Much of the data on plastics and their distribution has been derived from beach surveys, ship-board surveys and neuston trawls. Beach surveys are a convenient and valid method of qualitative identification of the composition of plastic waste in the marine environment because they are not only littered regularly by users but also because the floating plastic debris originating from vessels at sea may eventually end up on the beaches. However, not all plastic debris floats until it is stranded. Floating debris can sink if it supports sufficient sessile organisms or entangles enough animals to increase the density above that of seawater. Virtually nothing is known about debris on the seabed or its effects on the benthic invertebrate taxa, although SCUBA divers near boat harbours and docks in Alaska have observed crabs tangled in snarls of discarded fishing line (Fowler & Merrell, 1986). It has also been suggested that the debris may increase the substratum for sessile organisms (Carpenter & Smith, 1972; Winston, 1982). Jewett (1976) has reported that 57% of stations sampled by benthic trawls were contaminated with refuse consisting primarilary of plastic materials such as brown or green refuse bags, pieces of clear plastic (bait wrappers) and plastic straps used as cargo binding material. Feder et al. (1978) also reported the prevalence of plastic in benthic trawls of the south-east Bering Sea, most of which was probably discarded from fishing vessels. In open ocean waters, denser plastic debris (e.g. polystyrene) gradually sinks to the denser, cold mid-water layers where it attains neutral buoyancy and remains suspended in the water column. This is likely to result in substantial underestimation of the amount of plastic in the oceans since most studies report concentrations of plastics in surface waters only (Morris, 1980a).

False Bay is a large coastal embayment near Cape Town, South Africa, which has many recreational beaches popular with both local and overseas beachgoers, and Andrady (1988) reports that beach litter left behind by visitors is likely to be the most significant of all the land based sources of plastic debris which eventually finds its way to the sea.

The objectives of this study were two-fold. Firstly, to examine the distribution of subtidal macroplastics in False Bay in order to provide a base line data set which would assist in identifying sensitive areas and help formulate more rational strategies for future investigations; and secondly, to assess the impact of plastics on the benthic fauna.

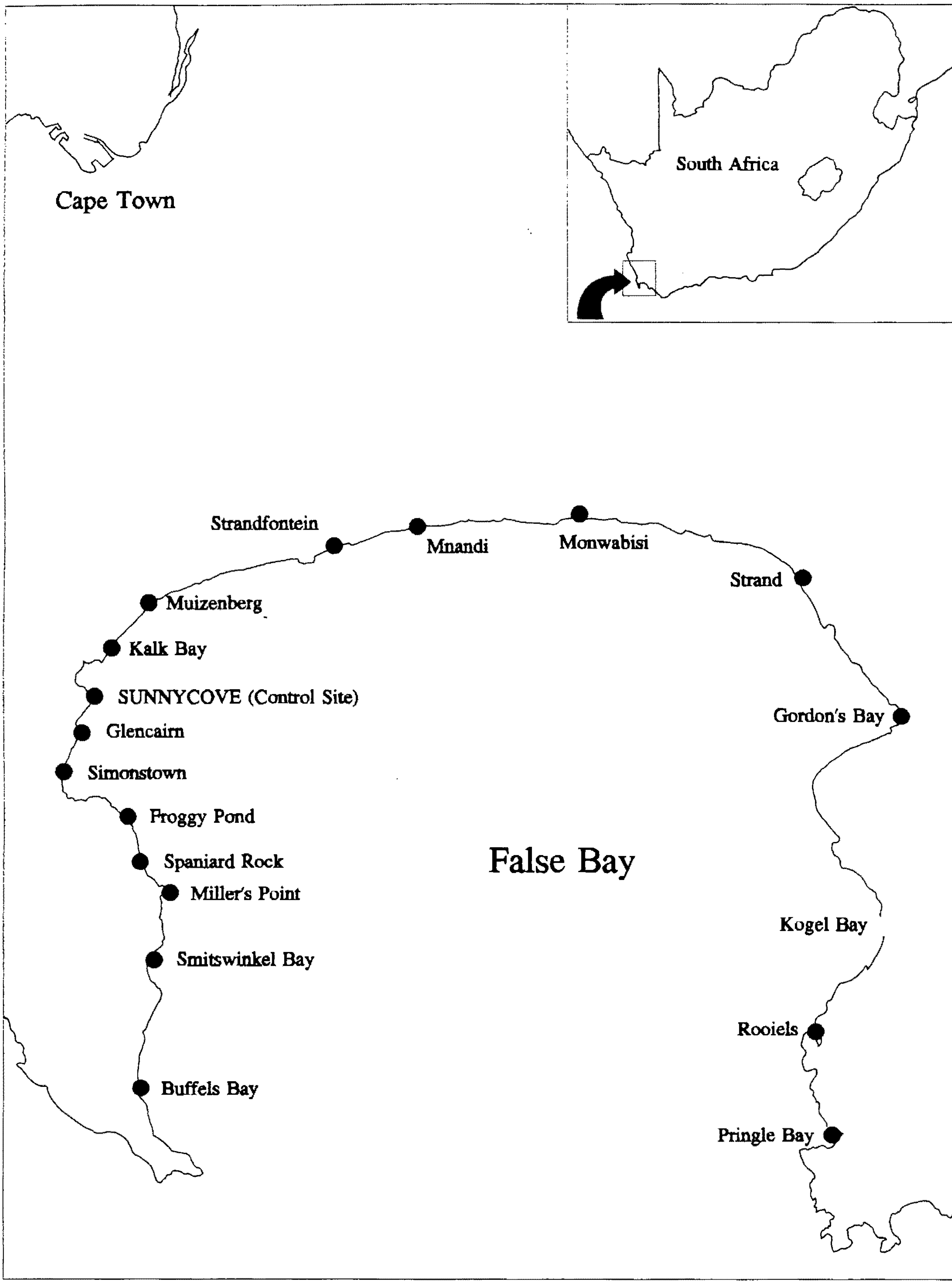


Fig. 5.1: Location of study sites for macroplastics survey in False Bay

STUDY AREA

Eighteen sites along the False Bay shoreline were selected for investigation, (see Table 5.1 and Fig. 5.1).

Table 5.1: Study Sites for Subtidal Macroplastics Survey in False Bay.

Western Shore	Northern Shore	Eastern Shore
Buffels Bay	Strandfontein	Gordon's Bay
Smitswinkel Bay	Mnandi	Kogel Bay
Millers Point	Monwabisi	Rooiels
Spaniard Rock	Strand	Pringle Bay
Froggy Pond		
Simonstown		
Glencairn		
Sunnycove		
Kalk Bay		
Muizenberg		

Seventeen of these sites were sampled twice, once in March 1991 and again in September 1991. In addition the Sunnycove site was selected as a control and was sampled every month from January 1991 until December 1991.

METHODS

Survey Method

SCUBA divers working under my supervision performed zig-zag transects across each site and collected all macroplastic fragments (> 20mm diameter) lying on the seabed. Actual time engaged in searching and collection was noted in order to standardise a catch per unit effort for each site.

Analysis

All plastic fragments were washed in fresh water, dried, weighed and categorised into one of four functional groups of 'user plastics' (after Ryan, 1989): packaging, fishing gear, plastic products and unidentified pieces. The fishing gear category consisted mainly of plastic squid jigs (monofilament nylon fishing line, which is difficult to quantify for comparative purposes, was not collected as part of the survey. However qualitative observations as to its abundance were made). Since by far the most plastic fragments were plastic packaging, this functional group was sub-divided further into: bags, bottles/jars/containers, packing straps, caps/lids, food wrapping, polystyrene and miscellaneous categories.

In some studies of floating plastic distribution (Day & Shaw, 1987), where microplastics such as industrial pellets are considered, the term density refers to the number of items per unit area and the term concentration refers to the mass per unit area. However, in the present study, where only macroplastics were involved, the distribution of plastic by mass was not considered due to the large variability in the mass of fragments. For example a few relatively massive pieces can influence mass estimates as opposed to number of pieces. The majority of particles were small (< 1.0mg) in all three types of user plastics.

Immersion

The duration of immersion of each particle in sea water was estimated as: short-term (< 1 week), medium-term (1-2 weeks) or long term (> 2 weeks). These durations were based on the results of a field experiment conducted at the Sunnycove control site (Fig. 5.1). Plastic supermarket bags were attached to the rocky substratum at 5 metres depth and checked once a week. It was found that the bags retained their colours and markings for the first week; after 1-2 weeks, markings became indistinct; and colonisation by benthic animals such as barnacles and mussels only became visible after two weeks. Such estimates can only be considered as a tenuous guide to duration of immersion since they do not take into account the initial floating period of the plastic before it sinks (during which time it is exposed to ultra-violet light), nor the abrasion caused when currents move the plastic across the rocky or sandy substratum.

Colour

All samples collected were colour coded while wet into one of five colour categories: white/clear, brown/red, yellow/orange, blue/green, grey/black.

Benthic Fauna

Fauna attatched to plastics was identified to species level where possible and the number of occurrences noted.

RESULTS

Plastic Densities

Figure 5.2 shows the total numbers of the various functional groups of 'user' plastics found on the seabed of False Bay. Plastic packaging (557 pieces) is by far the most abundant category.

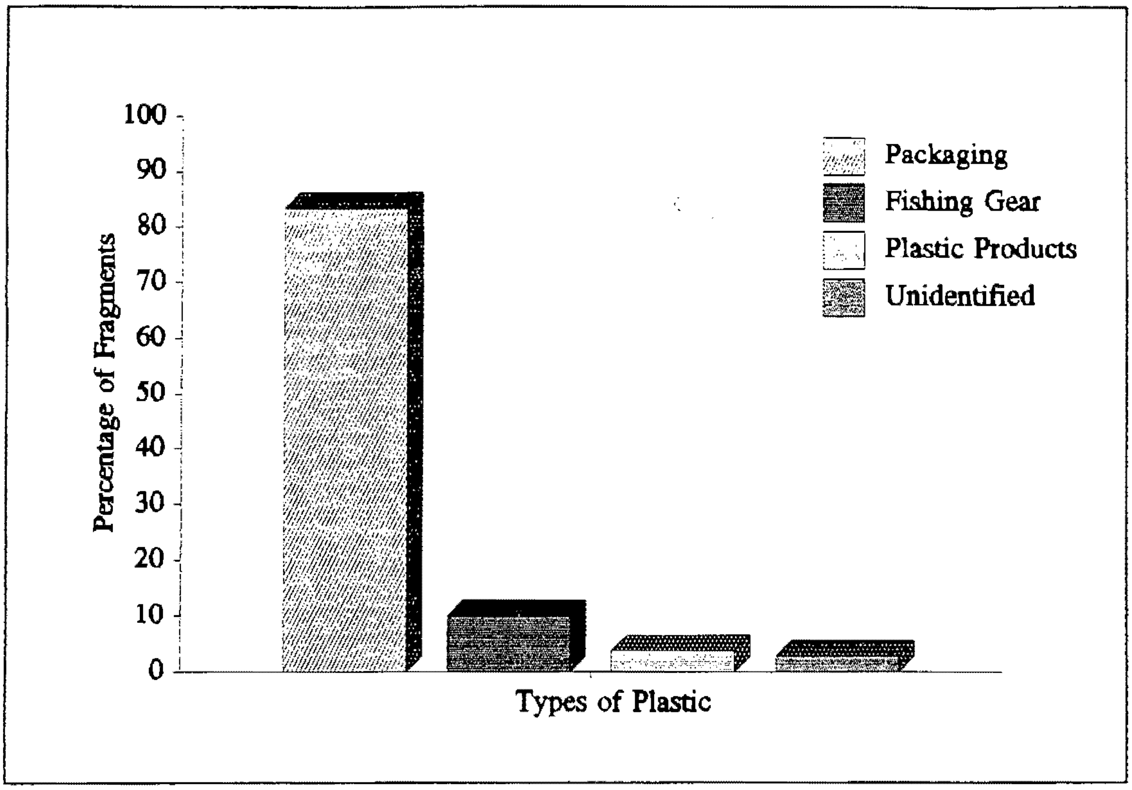


Fig. 5.2: Types of plastic showing percentage frequency

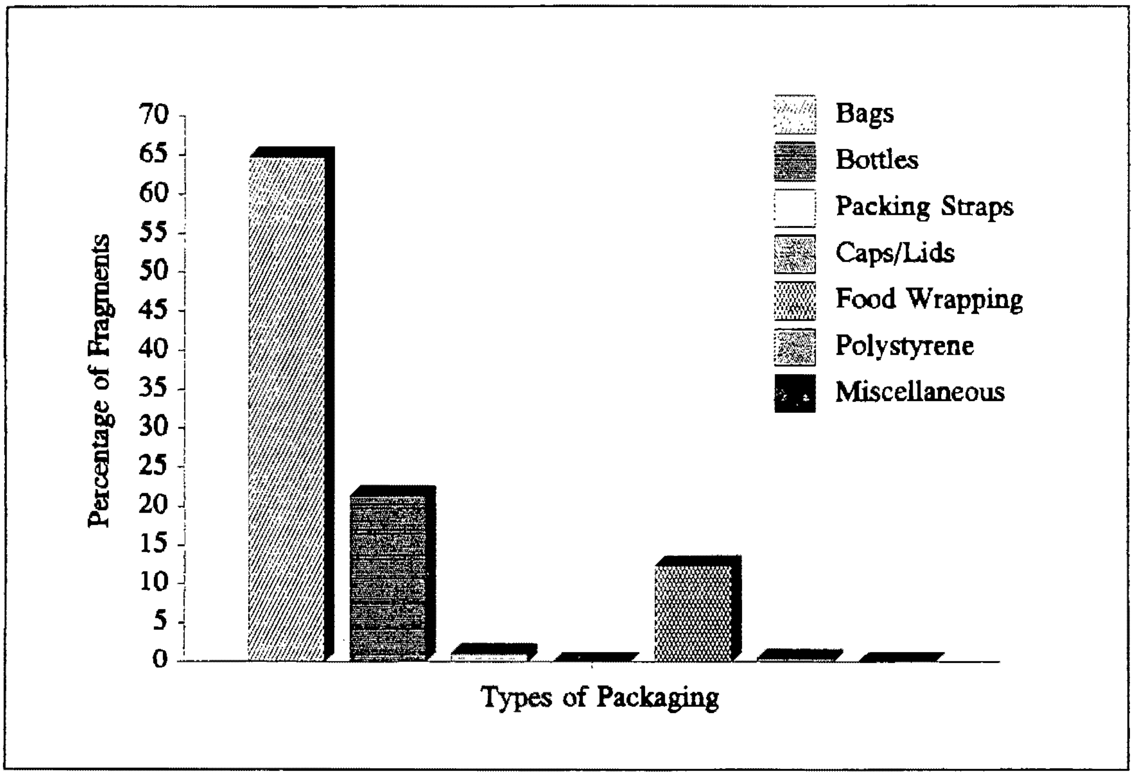


Fig. 5.3: Types of packaging showing percentage frequency

Figure 5.3 shows the breakdown of the types of plastic packaging. Plastic bags (361 pieces) are the most abundant type of packaging followed by bottles and jars (119 pieces) and food wrapping (69 pieces). Very few packing straps (6 pieces) or polystyrene fragments (2) were found. Although fishing line was not collected (see methods) personal observation indicated the greatest abundance of this material at the Kalk Bay and Gordon's Bay study sites. Figure 5.4 shows the monthly variation in the number of plastic pieces found at the Sunnycove control site between January and December 1991. Relatively few pieces of plastic were collected, with the highest number being in January.

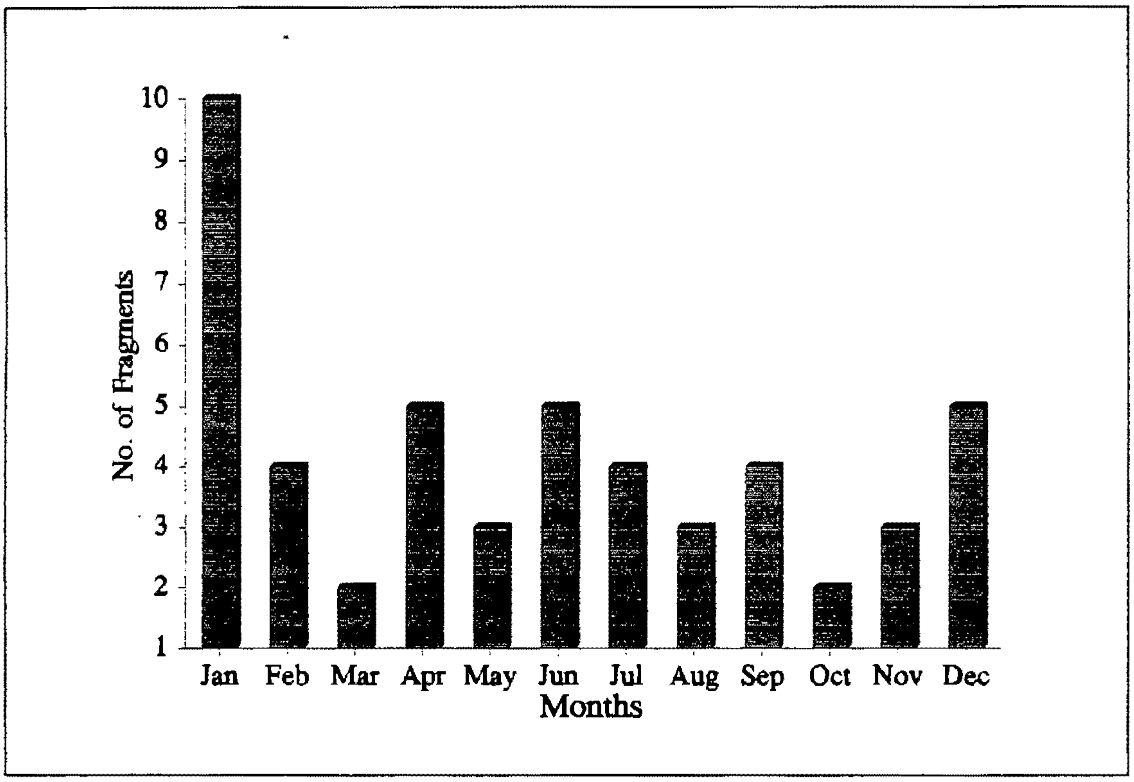
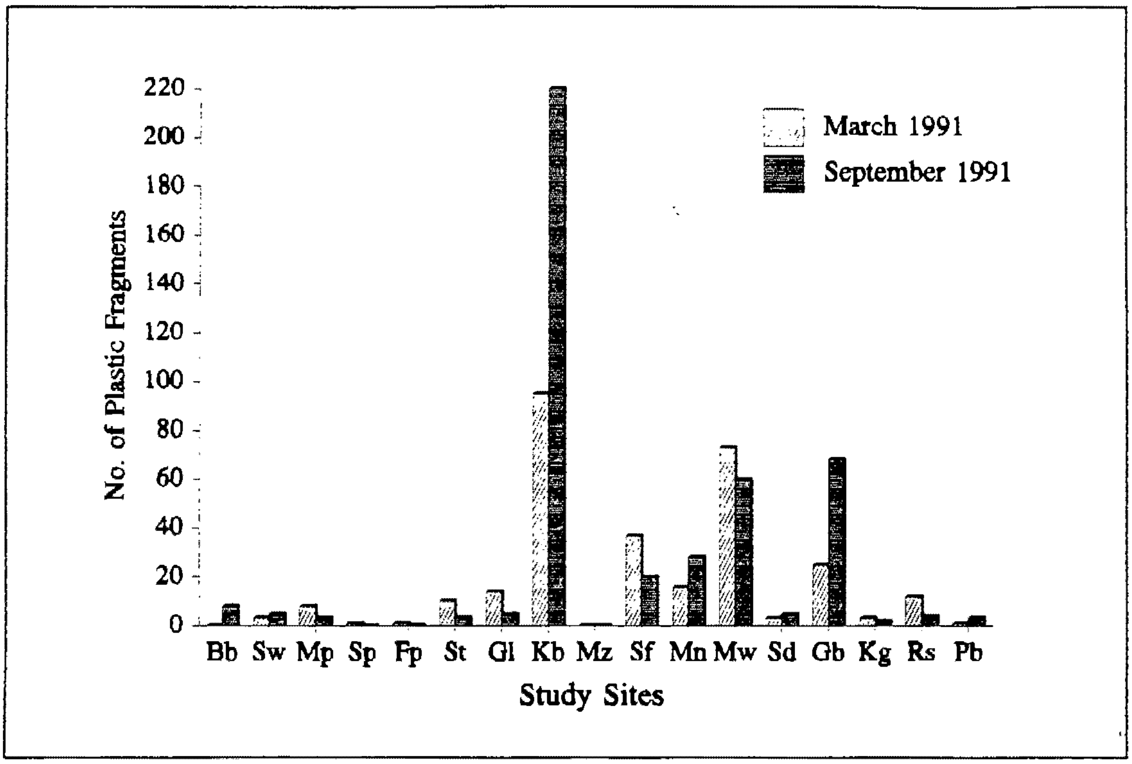


Fig. 5.4: Monthly variations in plastic density at the Sunnycove control site



KEY

Bb	Buffels Bay	Sf	Strandfontein
Sw	Smitswinkel Bay	Mn	Mnandi
Mp	Miller's Point	Mw	Monwabisi
Sp	Spaniard Rock	Sd	Strand
Fp	Froggy Pond	Gb	Gordon's Bay
St	Simonstown	Kg	Kogel Bay
Gl	Glencairn	Rs	Rooiels
Kb	Kalk Bay	Pb	Pringle Bay
Mz	Muizenberg		

Fig. 5.5: Autumn and spring variations in plastic abundance

Figure 5.5 shows the number of macroplastic pieces found at each of the seventeen stations for both the autumn (March) and spring (September) surveys. The highest density of plastic is found at Kalk Bay (on the eastern shore) with 95 pieces in March and 220 pieces in September. The next greatest density is at Monwabisi (on the north shore) with 73 pieces in March and 60 pieces in September. However, the total mass of plastic found at Monwabisi (1350g) was greater than that at Kalk Bay (660g). The plastic at Monwabisi consisted of fewer much larger fragments than at Kalk Bay, which had a greater number of smaller fragments.

Immersion

Most of the fragments at Kalk Bay had been immersed for a medium (42%) to long (57%) period whereas most fragments at Monwabisi had been immersed for a short (65%) period.

Colour

Figure 5.6 shows the percentages of plastic for each category of colour. Most pieces of plastic (67%) fell into the white/clear group. Colonisation of the plastic and interactions therewith (e.g. Parechinus) occurred 95% of the time on white plastic.

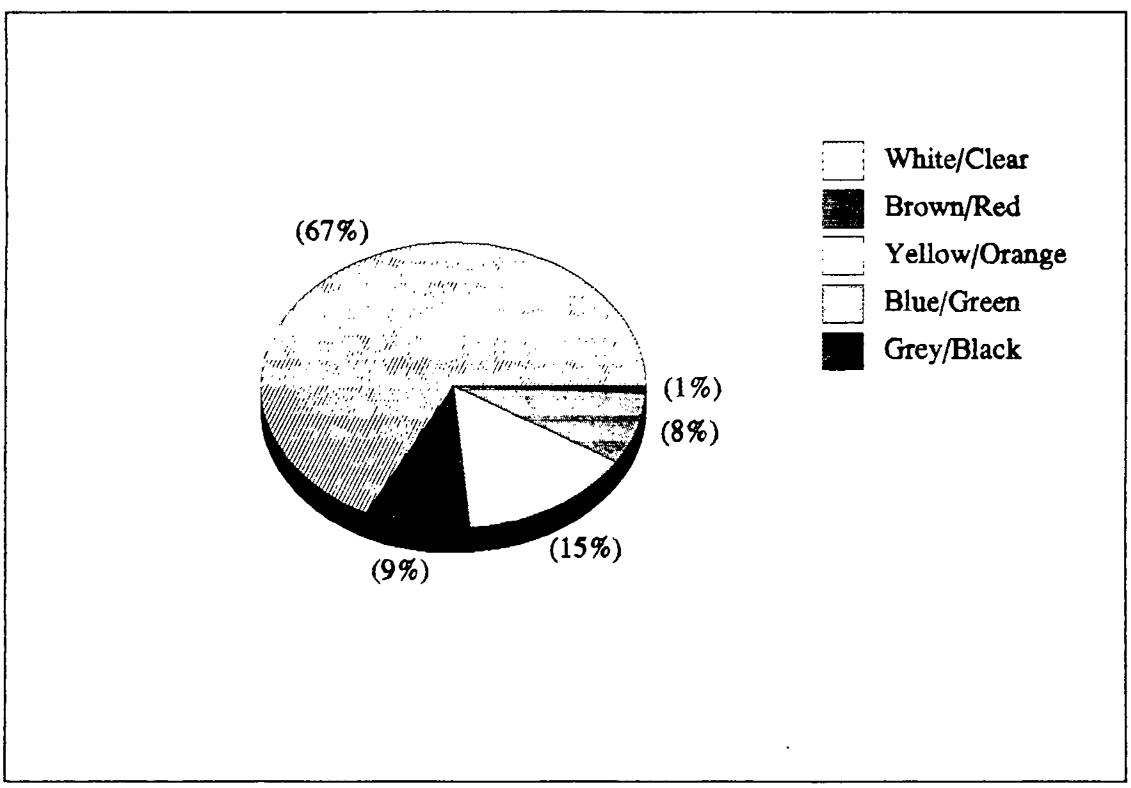


Fig. 5.6: Percentage occurrence of different coloured plastics

Benthic Fauna

Table 5.2 shows the number of occurrences of benthic fauna on plastic fragments.

There were forty-three observations at seven different sites of sea urchins (Parechinus angulosus) with plastic fragments attached. Twenty-eight pieces of plastic had the pink encrusting coralline alga Lithothamnion attached and the flexible, horny, central core or skeleton of the sea-fan Lophogorgia flammea was found on three occasions entangled in snarls of fishing line. There was only one occurrence of the anemone Bunodosoma capensis colonising on the surface of a large, white, partially buried plastic fertiliser bag at Rooiels. An anoxic black layer of sand was observed underneath the bag. Small specimens of both Choromytilus meridionalis and Balanus sp. were also found on plastic fragments at several sites (see Table 2.2 below).

Table 5.2: Species of benthic fauna found on plastics in False Bay.

Species	No. of occurrences with plastic
Cnidaria:	
Bunodosoma capensis	1
Lophogorgia flammea	3
Mollusca:	
Choromytilus meridionalis	19
Crustacea:	
Balanus sp.	23
Echinodermata:	
Parechinus angulosus	43
Algae:	
Lithothamnion	28

DISCUSSION

Ryan & Moloney (1990) found that plastic comprised more than 90% of artefacts on South African beaches, with densities of all types of plastic having increased significantly between 1984 and 1989. The greatest increase was in packaging and other disposal items, the vast majority of which are manufactured locally. The results of the present study confirm these findings, with plastic packaging (Fig. 5.2) making up 83.3% of the total number of plastics collected, and with one exception, all identifiable pieces of plastic were of local origin. The exception was a piece of packaging of Taiwanese origin which was probably originally dumped at sea by a fishing trawler. This was also the only piece of debris which could be positively identified as being of oceanic (i.e. disposed at sea) as opposed to land-based origin. Thus virtually all the plastic debris found in the present study entered the marine environment from local, land-based sources. Caulton & Macogni (1987) report that most of the smaller items of litter on beaches are discarded by visitors, and beach litter left behind by beachgoers is likely to be the most significant of land-based sources (Andrady, 1988) entering the marine environment. This litter is typical of that of a consumer-orientated society with its emphasis on pre-packaged goods.

In a study of Cape Peninsula beaches Van Herwerden & Bally (1989) found a dramatic decrease in the number of people attending the shore during winter and the period over which visits occurred was also abbreviated compared to summer beach attendance. They also report that weekday beach attendances were greatest during the annual December, or Christmas holidays, while weekend beach attendances were maximal during the summer months of January, February and March. This would explain the comparatively higher level of plastics found at the Sunnycove control site (Fig. 5.4) in January and December, which coincides with the peak holiday season when most litter is left on the beaches. However, the expected decrease in winter when beach attendances are low is not apparent and this could be due to the introduction of plastic debris via storm water drains as a result of the winter rainfall spates. There are also no clear-cut seasonal variations apparent from individual study sites (Fig. 5.5). Most plastic fragments were found 'trapped' under overhangs or boulders where the site had a rocky substratum and this entrapment by the seabed topography would appear to be a major mechanism controlling their distribution in False Bay. This is confirmed by the complete lack of plastic found at the Muizenberg site (Fig. 5.5), which has a sandy substratum. After a certain period of flotation plastics sink to the sea bottom and during both flotation, and sinking periods can be carried long distances by currents. Holström (1975) reported that fisherman in the Skagerrak regularly find plastics in their nets trawled at depths of 180-400 metres, and Bingel et al. (1987) found that the accumulation of plastic materials on the sea floor appears to be strongly correlated with basic oceanographic conditions in the Mediterranean region. The authors found that the highest accumulations in Iskenderun Bay off the Turkish coast occurred at the entrance, centre and innermost areas. They suggest that due to extreme resistance to decay the amount of plastics in the coastal marine environment will increase, and there are indications that large parts of these synthetics are transported to deeper waters. Oceanographic processes such as currents and winds obviously play a large role in the distribution of subtidal plastics in False Bay. Wind-forced longshore currents predominate on the north shore (CSIR, 1986) and one would expect much of the floating debris to end up in the Gordon's Bay corner of False Bay where it would be more likely to settle. Although the highest density of plastic on the north shore was found at Monwabisi, this was all recently introduced plastic, whereas 98% of the particles at Gordon's Bay had been immersed for a long period. This would suggest that plastic debris does tend to accumulate in the Gordon's Bay corner. It would seem, therefore, that although Strandfontein, Mnandi and Monwabisi are important source areas of plastic debris entering the waters of False Bay, longshore currents move debris towards Gordon's Bay where it tends to settle. This is confirmed by the large amounts of plastic litter washed up on the shore between the Strand and Gordon's Bay (C.D. Rundgren, pers. obs.).

Ryan (1989) suggests that seasonal differences in the amount of plastic floating at sea off the southwestern Cape can be attributed to the effects of wind. During summer consistent southerly trade winds move plastics onto the beaches of the south coast (accounting for low plastic densities at sea), whereas in winter plastic on beaches is released into the sea by wind and wave action (resulting in the low density of plastic on the beaches during winter). The present study indicates that subtidal plastics in False Bay are all introduced locally from the shores of the bay, and the comparatively low levels of plastic pollution suggest that litter not stranded on the beaches may well be entrained in currents leaving the bay. Much of this plastic may eventually be trapped in the slowly circulating gyre on the Agulhas Bank, although there is probably some interchange with the Agulhas Current. Ryan (1988a) suggests that high levels of plastic pollution entrained in the Agulhas Current may even be an important factor in introducing plastic particles to the southern ocean through mixing at the sub-tropical front.

Plastic constitutes 7-10% (by weight) of the controlled urban/waste stream (Stander & Benadé, 1990), but its low density, light-weight nature results in its volume being of more significance than its weight. Life spans of solid wastes in the marine environment are highly variable, depending on fabrication materials, physical conditions and rates of biological and chemical decomposition. Plastics cause most concern because of their widespread uses and intrinsic properties. These include low specific gravities (usually between 0.8 - 0.96), which causes them to float; non-biodegradability; and only slow photodegradability when exposed to ultra-violet radiation. In addition the lives of some thermo-plastics are extended by the incorporation of ultra-violet light stabilisers and anti-oxidants (Dixon & Dixon, 1981). Very little is known about the performance of plastics under marine exposure conditions, but Andrady (1988) found that polyethylene samples in sea water degrade at a much slower rate than those exposed in air. The tensile strength after a year floating on sea water showed no statistically significant difference from the average value of the starting (unexposed) polyethylene. Hence samples at sea were virtually unaffected. In the experiments trawl netting also did not show any significant variation in tensile properties due to type or duration of exposure. Trawl netting is compounded with adequate light stabilisers and designed to endure outdoor exposure and hence would persist longer in the marine environment. Wehle & Coleman (1983) suggest that submerged nets may remain in the ocean for up to 50 years. Nets are highly resistent to processes of degradation in the environment due to their minimum exposure to heat, light, and abrasion. The slower degradation rates of plastics in sea water are probably due to differences in heat build-up and fouling. Plastics exposed to sunlight undergo 'heat build-up' and hence reach higher temperatures than the ambient air. At sea they will not suffer from such heat build-up due to heat transfer and consequently may undergo slower oxidation and photodegradation. The primary requirement for enhanced photodegradability at sea is that the material floats, since even a few metres of water strongly attenuate UV light. The availability of light for the photoreaction might be restricted by rapid biofouling of plastic surfaces at sea, since within hours of immersion a microbial film covers the immersed surfaces. Within a few weeks moderate to heavy growth of algae becomes apparent and the process may continue with eventual colonisation of the surface by macrofoulants such as barnacles. Therefore fouling gradually restricts light available for photodegradation and plastic fragments may eventually sink under the weight of foulants and other debris which they entrap. The specific gravity of the material also determines whether it will sink to the bottom immediately or whether it will float on the surface waters. During the present study, only 11% of the plastics were colonised by benthic fauna (Table 5.2). This would suggest that the specific gravity of the material, rather than fouling, is more important in determining whether the plastic sinks to the bottom.

The impact of plastic on the marine environment ranges from general degradation in the aesthetic appeal of beaches and coastal waters to the more lethal consequences of entanglement and ingestion by marine animals. The ingredients used in the manufacture of plastics may also be toxic by ingestion, e.g. alkyl phthalate plasticisers used in flexible PVC packaging films, some inorganic pigments used as opacifiers or fillers (Fry et al., 1987) and possibly antioxidants used in polyolefins. It has also been suggesed that plastic debris picks up toxic compounds such as PCBs and DDT from water and transfers them to seabirds via ingestion (Carpenter et al., 1972). Some plastics, however innocuous in appearance, may contain toxic substances such as polychlorinated biphenyls (PCBs) as plasticisers, stabilisers, colourants, etc., which might be lost to the water through weathering and incorportated by marine life (Carpenter & Smith, 1972; Gregory, 1978a).

of persistent debris can be substantial. In the case of any endangered or threatened species, such as sea turtles, any level of impact is significant.

Most research has focussed on the impacts of floating debris, whether by entanglement or ingestion, and it is not known whether plastic material on the seabed positively influences the faunal colonisation of the soft bottoms, or has destructive effects because of eventual pollution. The present study indicates that colonisation of plastics is taking place by at least three species, viz., Bunodosoma capensis, Choromytilus meridionalis, Balanus sp. and the alga Lithothamnion (Table 5.2). A fourth species, the echinoderm Parechinus angulosus, is making active use of plastic fragments as a canopy, held by its tube feet. Branch & Branch (1981) report that some species of echinoderms use their tube feet to hold a canopy of shell fragments over the body. They suggest that the reaction seems to be a response to light, for if a strip of light is shone over an otherwise darkenend animal it rearranges the fragments, but it is more likely to be a means of camouflage. This substitution of plastic for shell fragments has also been noted by Kartar et al. (1973), who report that polychaete worms in the Severn Estuary have learnt to make dwelling tubes out of plastic pellets. Morris (1980b) also reports that 60-70% of the objects counted in a survey of floating debris in the eastern Meditteranean were made of plastic and Carpenter & Smith (1972) have reported the occurrance of diatom and hydroid populations on pellets from the Sargasso Sea and coralline algae, sepulid worms and benthic Foraminifera have also been found on pellets. Although a high percentage of benthic faunal interactions occurred on white plastic in the present survey this probably does not indicate a significant colour preference since the bulk of the plastic fragments collected in the study were white (Fig. 5.6). Therefore in the present study the effects of subtidal plastic have proved neutral or benign, except for three instances where the horny skeletons of sea fans (Lophorgorgia flammea) were found entangled in snarls of monofilament fishing line. The animals had been uprooted from the substratum by entanglement and the outer fleshy coenenchymes of the animals had been stripped off. This was as a result of recreational angling. The other possibly adverse effect was the smothering of the sediments and the creation of an annoxic black layer as observed in one instance at Rooiels. However, such occurrences appear unlikely in False Bay since they depend on a fairly large piece of plastic (in this case a $10dm^3$ fertiliser bag), sinking onto a sandy substratum, and the current movements in the bay seem to result in the bulk of the plastic being carried and entrapped in areas with a rocky substratum rather than a sandy one.

CONCLUSIONS

Although there are some 'hot spots' in False Bay where the densities of subtidal macroplastics are relatively high (Kalk Bay, Strandfontein, Mnandi, Monwabisi and Gordon's Bay), the overall densities in the sites examined were found to be low. The effects of plastic debris on the benthos were found to be largely benign, with some colonising of the debris by benthic organisms. Although most of the benthic fauna interactions took place on white plastic this does not appear significant since the bulk of the debris fell into this colour category. Most of the debris consisted of plastic packaging from local, land-based sources, which indicates that beach goers are responsible for the litter which is left on the beaches and is subsequently blown or washed into the sea. It is estimated that more than R10 million is spent annually on cleaning beaches in South Africa where plastic makes up more than 90% of all stranded debris (Ryan, 1989). However, only the most popular bathing beaches are cleaned regularly during the summer season to justify the expenditure, and hence beach cleaning is unlikely to have any significant effect on present levels or distributions of marine litter. Therefore the problem is seen as one of education at all levels in caring for the environment rather than ineffective and unenforceable measures. Since a large percentage of South Africa's population is illiterate and uneducated and yet has access to first world supermarkets and first world packaging, mostly plastic, littering of the environment is likely to persist for some time. A source reduction approach (Wirka, 1988) where attempts are made to reduce the amount of plastic used in disposable applications would probably be the most successful approach to the problem. However, the abundance of plastic would probably continue to increase even after the rate of input began to decline because of its long life span at sea, and Gregory (1978a, 1978b & 1983) has estimated that it would take three to fifty years for complete degradation of plastic on beaches, and much longer on the sea.

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CHAPTER SIX

SOME OBSERVATIONS ON THE SUBTIDAL MARINE ENVIRONMENT IN THE VICINITY OF THE MARINE OIL REFINERS EFFLUENT OUTFALL AT DIDO VALLEY, SIMONSTOWN

INTRODUCTION

There are four industrial outfalls of note which discharge into the waters of False Bay. Three of these (AECI, SOMCHEM, and Gants) are located on the north shore in the vicinity of the Lourens estuary (see Chapter Two, Fig. 2.2), and the fourth, the Marine Oil Refiners effluent discharge outfall is located on the western shore near Simonstown. Although some studies have been done on the AECI outfall (see Eagle, 1976) and the Gants outfall (see Bally et al., 1980), the restricted access in terms of the Official Secrets Act, has limited the research in this area. By contrast, the easily accessible Marine Oil Refiners at Dido Valley has been well studied (Brown, 1979, 1980, 1983a, 1983b, 1989, 1991), and over a long period of time. In contrast to the abundant literature on the acute ecological effects resulting from high impact, visible pollution, such as oil spills (see Brown, 1985, for a review) or the more insiduous effects of stormwater pollution (see see Augoustinos & Kfir, 1990; Brown et al., 1991), the latter having attracted particular attention in False Bay, the studies on the Marine Oil Refiners effluent discharge are of particular interest because there are few papers of value on long-term, sublethal pollution effects. Although Chapter Three examined the impact of the Steenbras Water Treatment plant discharge on the subtidal fauna of False Bay, this study was a comparative one between the impact site and two control sites on either side of it. As there was no baseline data set, there was no way of assessing whether the impact site per se had changed over the many years during which the discharge had been taking place. By their very nature sublethal pollution effects are not immediately apparent from casual, visual observation. Although comparative studies between an impact site and representative controls sites are of value, they tend to be indicative of spatial rather than temporal changes. The shoreline in the vicinity of the

Marine Oil Refiners site has now been studied for almost twenty years, the studies having concentrated on the intertidal zone in the vicinity of the outfall. Initially the discharge took place over the sandy beach but subsequently, in 1979, an outfall pipe was constructed across the rocky shore to the north of the beach and discharges directly into the surf zone. Thus the focus of studies has shifted from the sandy shore to the rocky shore in the vicinity of the discharge point. Although the subtidal area in the vicinity of the outfall has been examined by divers on two occasions (see Brown, 1979, 1989) these studies were non-quantitative, and merely tried to establish if there had been some highly visible changes in the subtidal environment. Although one of these dives (see Brown, 1989) conducted by the present writer, indicated no immediate effects of pollution, it was decided to examine the same site over a period of three years in order to establish whether any gradual changes, which might have gone unnoticed, have taken place as a result of the discharge.

STUDY AREA

The Marine Oil Refiner's effluent outlet pipe (at Dido Valley, between Glencairn and Simonstown) enters False Bay approximately two hundred metres north-west of the wreck of the Clan Stuart (1917), which lies about 100 metres offshore in 6 metres - 8 metres depth (Fig. 6.1). Co-ordinates of the point of entry of the effluent pipe are 34° 10' South, 18° 26' East.

Subtidally the substratum consists of sand with a few isolated rocks in the vicnity of the outfall, and the wreck of the Clan Stuart further offshore.

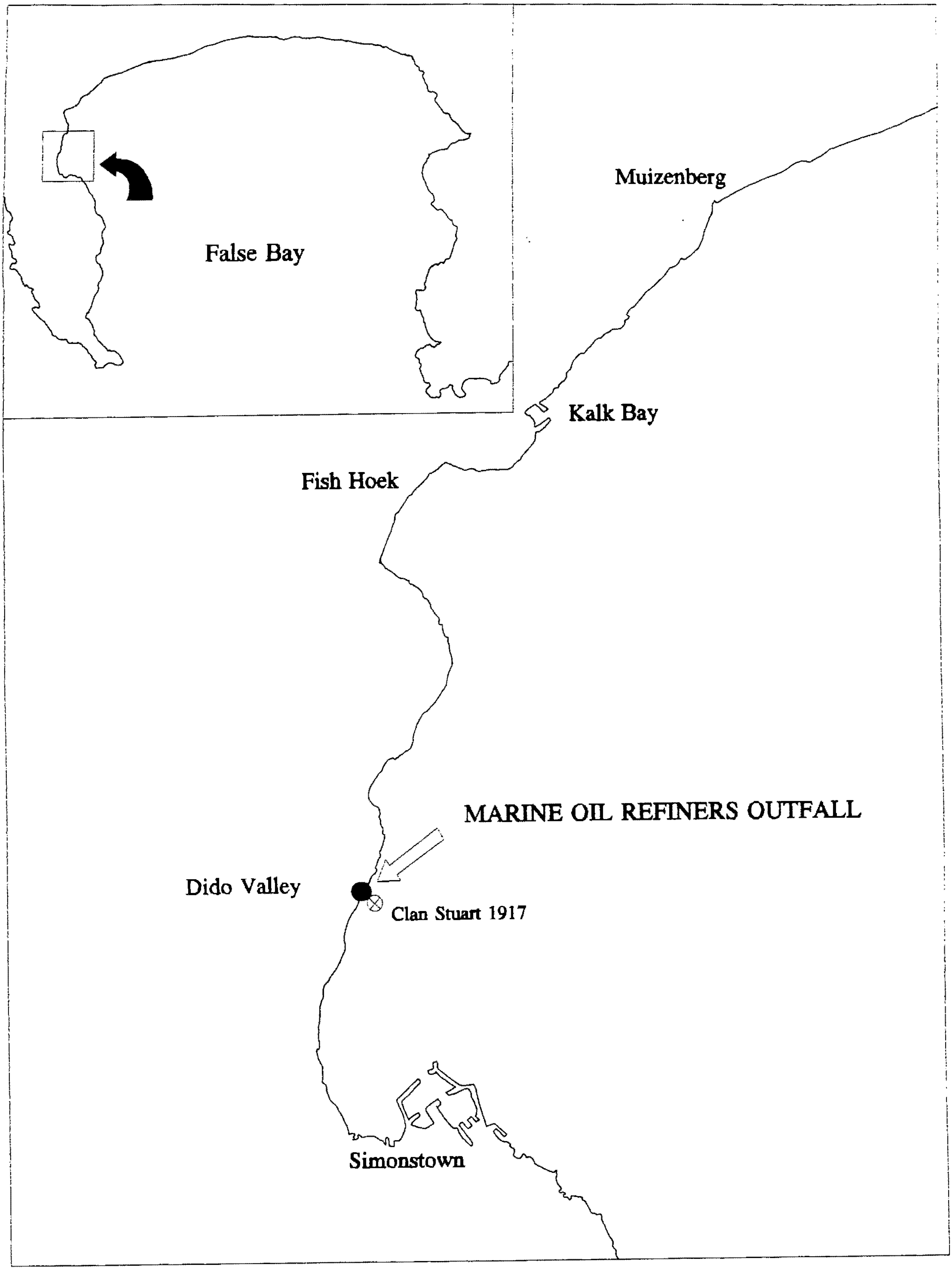

Fig. 6.1: Location of Study Site near Dido Valley, Simonstown

METHODS

SCUBA dives were conducted under my supervision in December 1989, December 1990 and December 1991. On all three occasions, calm conditions (< 5 knots wind) were chosen for improved visibility (in all cases visibility varied between 5 - 7 metres). In each case a transect was taken from the outfall to the wreck of the Clan Stuart which lies to the south-east (see Fig. 6.2).

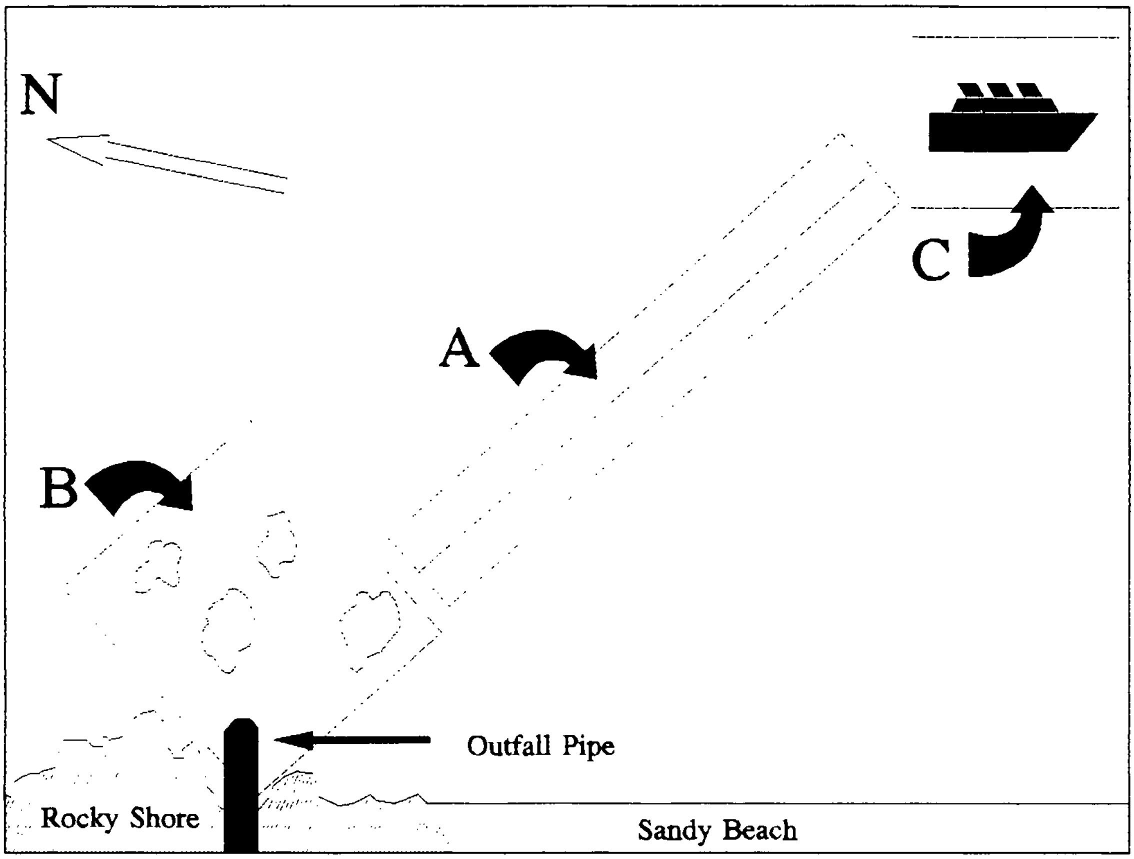

Fig. 6.2: Sketch map of the subtidal study area

Visual observations of species were made and recorded in situ, but no samples were removed since removal would have profoundly affected species composition in the few highly localised areas where the subtidal biota occurred. For ease of comparison the observed species were categorised according to three areas of occurrence, viz.

Area A) The sandy substratum, 1 metre either side of a transect between the end of the outfall pipe and the wreck of the Clan Stuart.

Area B) Isolated rocks on the sandy substratum in the vicinity of the outfall.

Area C) The wreck of the Clan Stuart

RESULTS

The chemical constituents and parameters of the Marine Oil Refiners effluent are shown in Table 6.1. These values are reported by Brown (1983b) as being the average values for effluent analyses during 1983. On the first dive of the present study, in December 1989, a comprehensive species list was drawn up (Table 6.1). This was used as a baseline for comparisons on the subsequent dives in 1990 and 1991. The presence or absence of a species is indicated by a 'yes' or 'no' in the appropriate column.

Table 6.1: Average values for the Marine Oil Refiners effluent analyses (from Brown, 1983b)

PARAMETER	AVERAGE VALUE (1983)
Oxygen absorbed (OA)	150 $mgm.l^{-1}$
Chemical oxygen demand (COD)	1410 $mgm.l^{-1}$
pH	8.9
Fats and oils	17 $mgm.l^{-1}$
Susupended solids	6 $mgm.l^{-1}$
Glycerol	0.14%
Nitrogen	25 $mgm.l^{-1}$
Nickel	0.24 $mgm.l^{-1}$

From Table 6.1 it should be noticed that the chemical oxygen demand is fairly high and the nitrogen content low.

Table 6.2: List of species observed (December 1989) categorised according to area of occurrence

TAXON	SANDY SUBSTRATUM (A)	ROCKS ON SAND(B)	WRECK (C)
Porifera:			
Polymastia mammillaris	No	No	Yes
Cnidaria:			
Pseudactinia flagellifera	No	No	Yes
Anthopleura michaelseni	Yes	Yes	No
Anthothoe stimpsoni	No	No	Yes
Bunodosoma capensis	No	No	Yes
Bunodactis reynaudi	Yes	Yes	Yes
Bryozoa:			
Alcyconidium nodosum	No	No	Yes
Mollusca:			
Aulacomya ater	No	No	Yes
Burnupena catarrhacta	No	No	Yes
Burnupena delalandii	Nc	No	Yes
Burnupena papyracea	No	No	Yes
Choromytilus meridionalis	No	Yes	Yes
Dinoplax gigas	No	Yes	Yes
Nucella squamosa	No	No	Yes
Patella barbara	No	No	Yes
Patella miniata	No	No	Yes
Crustacea:			
Jasus lalandii	No	No	Yes
Ovalipes punctatus	Yes	No	No
Plagusia chabrus	No	No	Yes
Echinodermata:			
Henricia ornata	No	No	Yes
Marthasterias glacialis	No	No	Yes
Patiria granifera	No	No	Yes
Patiriella exigua	No	No	Yes
Parechinus angulosus	No	No	Yes
Chordata:			
Pyura stolonifera	No	No	Yes
Algae:			
Corallina sp.	No	No	Yes
Ecklonia maxima	No	No	Yes

Both the second and third dives (December 1990 and December 1991) illustrated no increase or decrease in species richness in any of the three study areas, all species identified on the first dive, 1989, remaining constant. It is clear that area C, around the wreck, is far richer in species than either areas A and B. Except for two species of anemone the only other species seen over the sand was the burrowing crab, Ovalipes punctatus. Area B (mixed rock and sand) only had four species whereas the wreck area C had twenty-five species.

DISCUSSION

In conjuction with the present observational study it is appropriate to examine previous toxicity work. The effluent has previously been tested on various animals (see Brown 1979). Its toxicity to Bullia digitalis was found to be no greater than that caused by dilution with fresh water (Brown, 1982), and in fact individuals of Bullia digitalis kept in up to 10% effluent for some weeks appeared to be in better condition than the controls. Since the effluent contains mainly glycerol and fatty acids (Table 6.1) Brown (1982) suggests that animals unfed during the course of the experiment were possibly able to absorb these substances, a source of nutrients denied to the controls. Other toxicity tests on the gametes and embryos of the sea-urchin Parechinus angulosus, adult Gastrosaccus psammodytes, a variety of fish larvae and on the heart-rate of Choromytilus meridionalis showed that the effluent had a very low, short-term toxicity comparable to that of dilution by fresh water (Brown, 1979). Bacteriological studies have also indicated that there is no serious peturbation of marine bacterial flora in the nearshore zone (Brown, 1979), and it appears that the most serious potential impact of the effluent on the marine environment is from the high oxygen demand of the effluent (Table 6.1) and its potential for lowering the oxygen content of the sea water (Brown, 1979).

One of the most striking features to emerge from the present study was the depauperate species diversity in all areas except around the wreck (Table 6.2). This is consistent with previous observations on the subtidal ecosystem (see Brown, 1979, 1989). Except for the burrowing crab Ovalipes punctatus, there appeared to be a complete absence of any permanent subtidal fauna. Even the temporary infaunal species, such as Isopoda and Mysidacea, reported previously (Brown, 1979) were not observed during the present study. Brown (1983b) reports that both the cirolanid isopod Eurydice longicornis and mysid Gastrosaccus psammodytes, which were absent on the beach prior to 1979, have recolonised the area since the effluent was re-routed to the rocky shore. Since the reversal of their positive rheotaxic response is a sensitive indicator of pollution (Brown & McLachlan, 1990) and enables them to migrate away from affected areas, their presence indicates that the sea water in the area is unpolluted. The impoverished meiofauna is a direct result of lowered salinity and not primarily due to pollution (Brown, 1983b). Further evidence of the low impact of the effluent in the area is given by Brown (1991) who reports that some recognisable individuals of the species Bunodactis reynaudi have remained in the same area and continued to flourish for over twelve years. However, in the present study, the absence of the macrofauna subtidally, may be a consequence of the dynamic nature of the sediments in the area, rather than being directly related to the impact of the effluent. The subtidal sand level displays a seasonal fluctuation of up to a metre (Brown et al., 1991), with the summer south easterly winds and their associated currents resulting in onshore accretion of the sediments. Conversely, the winter north westerlies result in transport offshore. Thus the biota in this area is subjected to high levels of stress from both abrasion and smothering effects. It is likely that these harsh environmental factors affect the species composition more than the effluent. The present study confirms that the only species occurring in any abundance in the immediate area of the outfall are Bunodactis and Choromytilus, both of which are adapted to sandy conditions (see Day, 1974). However, by their very nature, these species are obviously also more likely to be resistant to pollution stresses. Both the gastropod Bullia digitalis and the bivalve Donax serra, which are common on sandy beaches displaying similar exposure to wave action, in other parts of False Bay (see Brown 1971), were notably absent from the study area. Brown & McLachlan (1990) suggest that the nature of the swash climate is a key factor in determining the distribution of the sandy beach macrofauna in general. The immediate area of the outfall has several rocks protruding above the sand surface and Brown et al. (1991) suggest that such a substratum severely alters the nature of the swash in its vicinity, changing current patterns and increasing turbulence, thus making it difficult or impossible for burrowers such as Bullia and Donax to bury themselves before the next swash carries them away. Such turbulence was noticable on all three occasions, as it affected the divers in the immediate area of the outfall. Despite this, small individuals of Choromytilus were observed in the present study on the rocks close to the discharge point. This indicates that recruitment is taking place, which is a healthy sign. Although Brown et al. (1991) report the absence of two groups of animals (Porifera and Echinoidia) from the shore, representatives of both groups were identified on the wreck (Table 6.2).

CONCLUSION

Despite the poor siting of the Marine Oil Refiners of Africa factory and its effluent pipe in an area where any pollution is likely to become trapped in the large, nearby Simon's Bay, there is at present no evidence of this occurring. The low nitrogen content of the effluent is also unlikely to cause the unsightly but harmless plankton blooms which are a feature of the north shore of False Bay. The low species diversity in the immediate vicinity of the discharge point is probably not indicative of the effluent impact, as previous tests have indicated that toxicity is low. The lack of subtidal macro fauna is more likely due to the harsh environmental conditions (abrasion and smothering), rather than pollution impact. Nearby, an abundant, healthy and diverse community exists in the region of the Clan Stuart (1917) wreck which is indicative of a stable ecosystem. Although periodic complaints concerning the odour of the effluent and the presence of a floating scum on the sea surface are made by local residents, particularly during north-westerly winds when the effluent gets carried into Simons Bay, there is at present no evidence to suggest any toxic effects. It is, however, imperative that the chemical parameters of the effluent remain constant and the discharge volumes are not increased. No recurrence of the large spills from the factory that occurred in 1988 and 1989 should be tolerated. Although a longer submarine outfall extending further out into False Bay may be aesthetically more pleasing in terms of visible pollution it is possible that the subtidal benthic biota is at present protected by the rise of the effluent to the surface. However, there is also the possibility that the neuston is more at risk, and this should be researched further.

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CHAPTER SEVEN

THE PHYSICAL CIRCULATION PATTERNS OF FALSE BAY AND THEIR ROLE IN THE DISPERSAL OF POLLUTANTS

INTRODUCTION

Central to any discussion of pollution in False Bay are the physical processes that govern water movement and hence dispersion of pollutants entering the Bay. Although an initial dilution of effluent from a discharge point occurs on first contact with sea water, it is the secondary dilution resulting from the mixing and dispersal of the effluent field by the prevailing ocean currents which assumes paramount importance in a semi-enclosed system such as False Bay. Hence a consideration of the current regime in False Bay is essential to the understanding of the dispersal of any effluent entering the bay.

Although False Bay has periodically been the focal point of research symposia (1968 - see Trans. Roy. Soc. S. Afr. Vol 39(2), 1970; 1980 - see Gasson, 1980; 1989 - see Trans. Roy. Soc. S. Afr. Vol 47(4&5), 1991), as Lutjeharms & Brundrit (1989) point out, very little understanding has been gained of the physical circulation of the water in the bay. This impression is reinforced by the recent review of the physical oceanography of False Bay by Gründlingh & Largier (1991). These authors suggest that the paucity of data on the circulation patterns of False Bay means that our insights into the characteristics of the bay are necessarily limited. However, in order to understand the dispersal of pollutants, it is appropriate to examine the salient features of the existing knowledge concerning the circulation patterns of False Bay, even though our understanding at present is flawed by an inadequate database.

HISTORY OF RESEARCH

The earliest recorded current measurements in False Bay were those carried out by the Division of Sea Fisheries from 1953 - 1963, employing drift cards (Atkins, 1970a). Although the percentage recovery of cards was low (5%), the results suggested that a west-flowing current entered False Bay in the summer, probably on the Cape Point side.

However, it was the pioneering investigations of Atkins (1970a, 1970b, 1970c) that provided the first real insight into the bay circulation. Between 1963 - 1969 as part of the Cape Town University based Marine Effluent Research Unit's False Bay investigations (see Atkins, 1970c), he carried out the first extensive study of the physics of the Bay (Lutjeharms et al., 1991). One of the most important features of Atkins' work was that by employing a "dye bomb" technique from aircraft, he provided the first nearly synoptic pattern of currents over a wide area. The scope and extent of his investigations have not been equalled to the present day, and much of the subsequent research on the physical circulation of False Bay has tended to both confirm, or build on, many of his findings.

The salient results of his investigations were to establish four "types" of circulation in False Bay (Table 7.1 & Fig. 7.1):

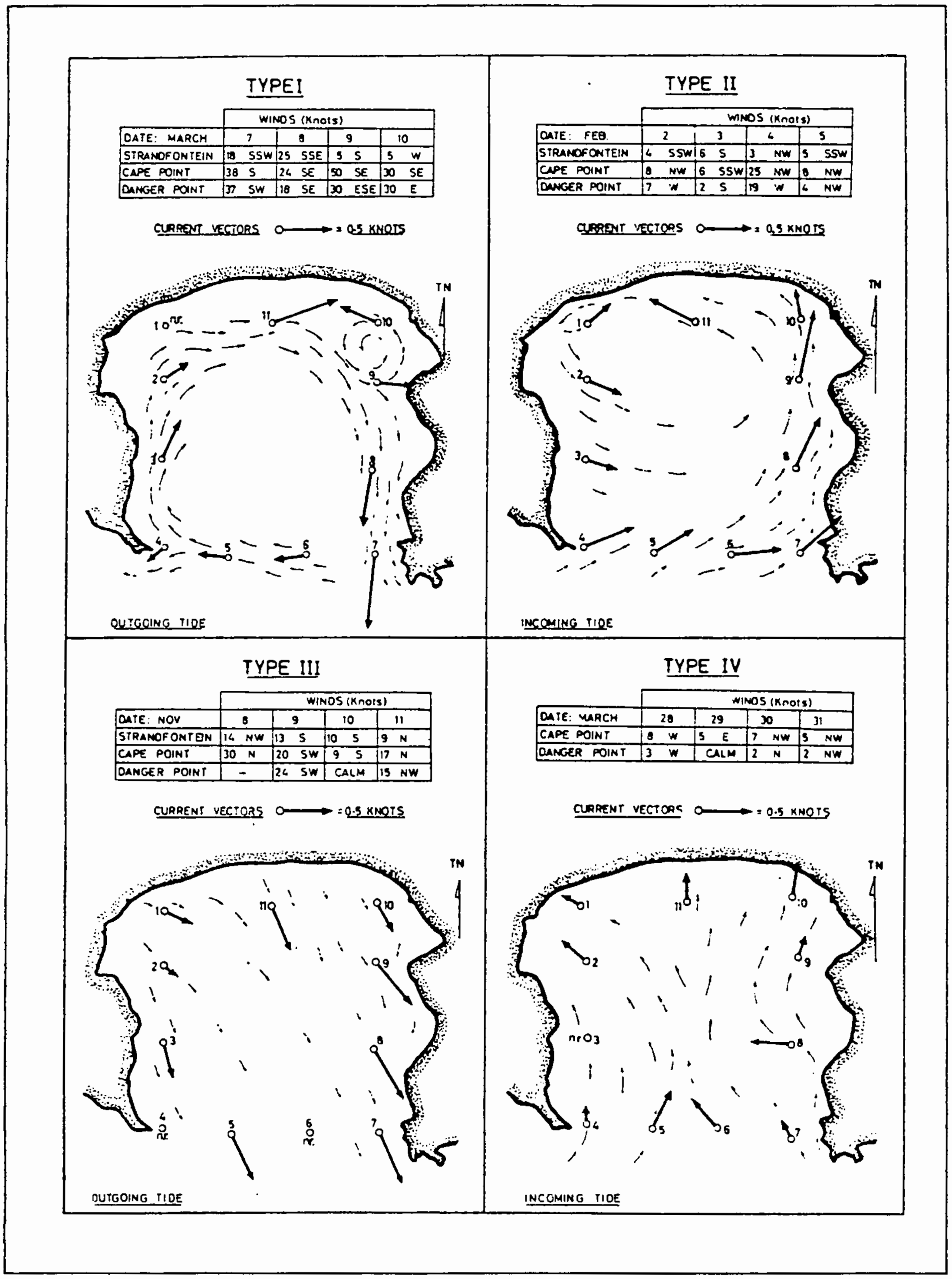

Fig. 7.1: Circulation patterns in False Bay (from Atkins, 1970a)

Table 7.1: Circulation patterns in False Bay (after Atkins, 1970a).

Type 1	A clockwise flow under south-east or easterly winds was the predominant circulation pattern in the bay.
Type 2	An anticlockwise flow under north-westerly winds.
Type 3 & 4	Tidal currents dominated during calm wind conditions, setting mainly north during flood and south during ebb.

Other noteworthy results were:

i) Smaller eddies (e.g. at Gordons' Bay) with circulations independent of the main bay circulation e.g. anticlockwise as opposed to clockwise (Atkins, 1970a).

ii) An estimated "residence time" of 4-6 days (Atkins 1970c).

iii) A marked stratification/thermocline in summer (Atkins, 1970b).

iv) Bottom currents were extremely variable in both direction and strength (Atkins, 1970a).

v) The possibility of a natural oscillation period in False Bay due to its nearly rectangular basin shape and uniformly sloping sea bed (Atkins, 1970a).

Cram (1970) confirmed the upwelling postulated near Cape Hangklip (Stander & Nepgen, 1968) and in the central region of the bay (Atkins, 1970b). He used airborne infra-red radiation thermometry (ART) to identify cold water plumes stretching from Cape Hangklip north-westwards into the central bay area, and suggested that they were caused by wind induced upwelling off Cape Hangklip. Subsequently, extensive marine fouling on a current meter deployed in the vicinity of Cape Hangklip (Gründlingh et al.,1989) has also suggested the existence of upwelling in this area. More recent work by Taljaard (1991) on nutrients suggests that nutrient rich bottom water is introduced into False Bay from the Agulhas Bank and surfaces near the centre of False Bay during light southerly winds. She suggests that the mechanism for this upwelling is the vortex caused by the postulated clockwise circulation in the bay. This is the same mechanism originally suggested by Atkins (1970b) who attributed the low temperature central water to the clockwise circulation in the bay and a possible vortex caused by the Whittle Rock area. Localised upwelling is also in evidence where the topography enhances the south-east wind, e.g. at Gordon's Bay, in the north-eastern corner of the bay (Marchand, 1932; Grindley & Taylor, 1964 & 1970). The clockwise current pattern inferred from the results of Cram's (1970) ART data also correspond closely with Atkins (1970a) Type 1 circulation. The widespread distribution of plastic drift cards from one point in False Bay has also been explained by a cyclonic movement in the bay (Duncan & Nell, 1969).

During the 1980's the employment of modelling techniques (Van Foreest & Jury, 1985) and more sophisticated equipment, such as continuously recording current meters (Wainman et al., 1987; Gründlingh et al. 1989; Nelson et al., 1991), and drifting radio-transmitting buoys (Botes, 1988) provided new insights into the physical circulation of False Bay, particularly the long period (subtidal) variations. Van Foreest & Jury (1985) suggested that the circulation in False Bay is predominantly wind-driven, and stressed the important influence of the Kogelberg on the south-easterly winds which dominate during summer. However, in investigating the wind-driven circulation, tidal currents were not taken into account by their model. The numerical model (Van Foreest & Jury, 1985) predicts weak anticyclonic flow with north-westerly winds, simple cyclonic motion due to south-westerly winds, and eddies arising from the wind shadowing effect of the Kogelberg. However under south-easterly winds (the main summer meteorological forcing) the model predicts a general anti-clockwise circulation compared with the clockwise circulation observed by Atkins (1970a). This probably due to the limitations of the model and its sensitive response to south-easterly and south-westerly winds (Gründlingh et al., 1989). In an attempt to make the first observations of the deeper circulation in the bay and to compare them with the surface circulation patterns described by Atkins (1970a) and the general depth-averaged circulation predicted by the Van Foreest & Jury (1985) model, Wainman et al. (1987) made the first synoptic current measurements by deploying four current meter moorings in the bay. Their results confirmed the flow previously observed during the two prevailing windfields: clockwise flow during south-easterly winds (confirming results of Atkins, 1970a) and anti-clockwise flow during north-westerly winds. Their results also indicated a southward flow on the east and west sides of the bay near the bottom. They suggest that this southward motion near Cape Point means that whole bay cyclonic motion cannot occur and postulate that water presumably enters the bay over some zone between Cape Point and Cape Hangklip, and leaves on the eastern and western sides. The lagrangian current measurements in the north of the bay made by Botes (1988) employing drifting radio transmitting buoys also indicate that a narrow southerly outflowing current exists on the eastern side of False Bay, and that the circulation of the central bay area is relatively stagnant (Fig. 7.2). He suggests that the ever present foam and debris line along the eastern coastline is a good indication of this southerly flowing current which is probably less than 500 metres wide.

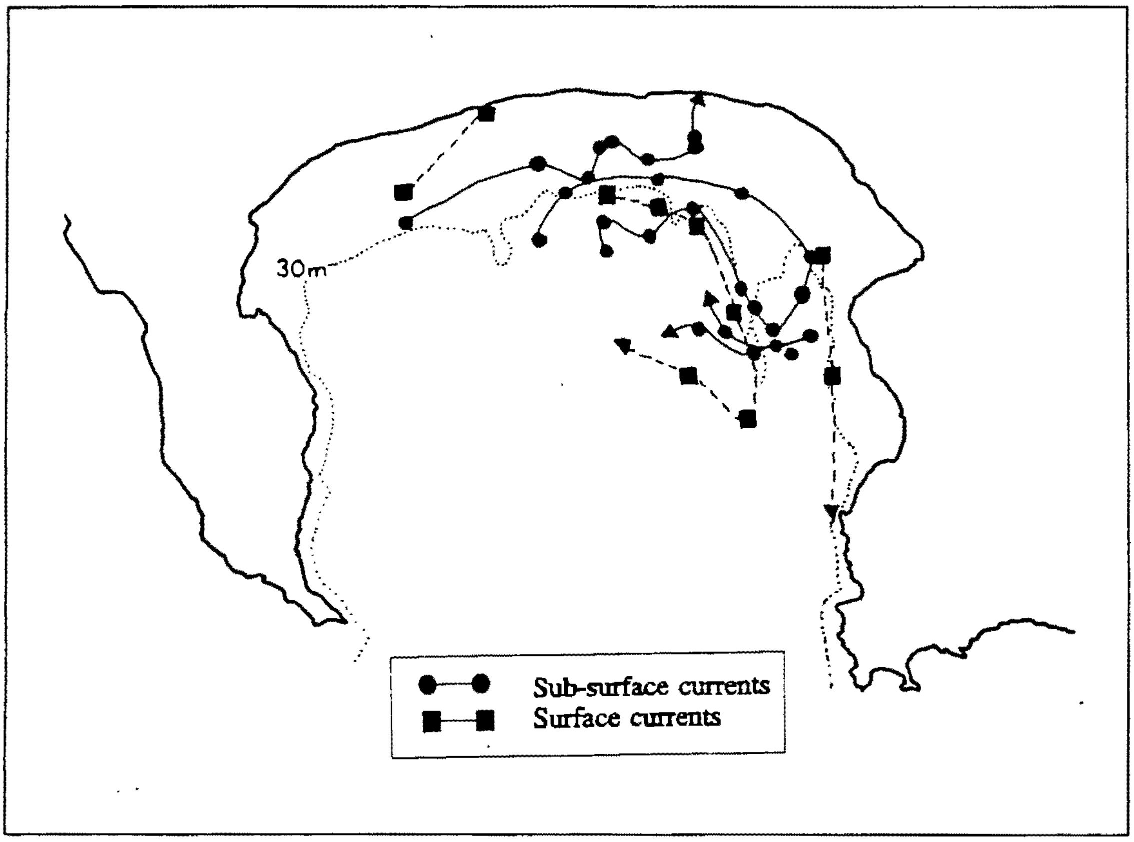

Fig. 7.2: Tracks of surface and subsurface drifters in False Bay (After Botes, 1988)

The latter results are consistent with the currents that can be inferred from the studies of Glass (1980) and Flemming (1982) on the bottom sediments in False Bay and their mean grain size diameter (Fig. 7.3). The coarse sand fraction, which is probably associated with high currents, is found close inshore along the coast from Fish Hoek to Cape Point (consistent with the current meter results of Wainman et al., 1987 and Nelson et al., 1991) and close inshore along the coast from Cape Hangklip to Kogel Bay (consistent with Botes, 1988 current drifter results). Another band of coarse grain sediments stretches across the north-eastern corner of the bay from near the Steenbras River mouth diagonally across to near Swartklip.

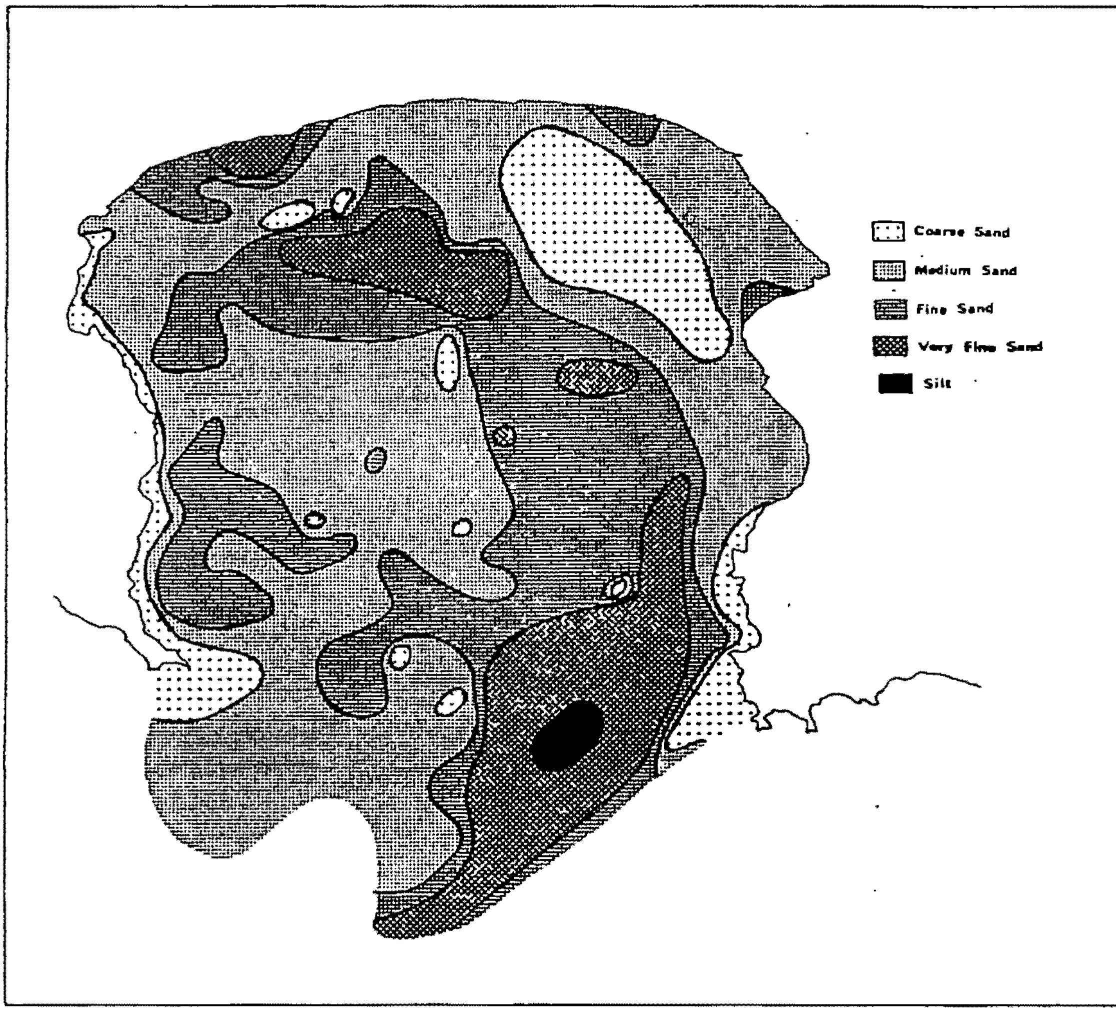

Fig. 7.3: Distribution of mean grain size diameters of the sand fraction (After Glass, 1980)

This is consistent with the postulated cyclonic circulation (Atkins, 1970a) which appears to bypass and isolate the more stagnant Gordon's Bay corner of the bay. Subsequent results from a line of current meters (Fig. 7.4) placed across the mouth of the bay (Gründlingh et al., 1989) have further confirmed this cyclonic circulation postulated by Atkins (1970a). In the vicinity of Cape Point the average currents were directed into the bay, veering clockwise at the locations further eastward, until they were directed in a southerly direction at Cape Hangklip (Gründlingh et al., 1991). In contrast, the more recent results of Nelson et al. (1991), obtained from a current mooring at the mouth of False Bay, indicate a south-westward current below 30m flowing out of the bay which corroborates the earlier work of Wainman et al. (1987) and is consistent with the predictions of the wind driven model of Van Foreest & Jury (1985). The results of Nelson et al. (1991) further indicate that in summer water leaves the south-western side of bay over most of the water column except the surface. They explain the apparent contradiction between their results and those obtained from a current meter situated further north (Fig. 7.4), which confirmed cyclonic circulation (Gründlingh et al., 1989), by suggesting that the water either leaves the bay along the western perimeter in a very narrow strip, or that the flow pattern varies seasonally or inter-annually.

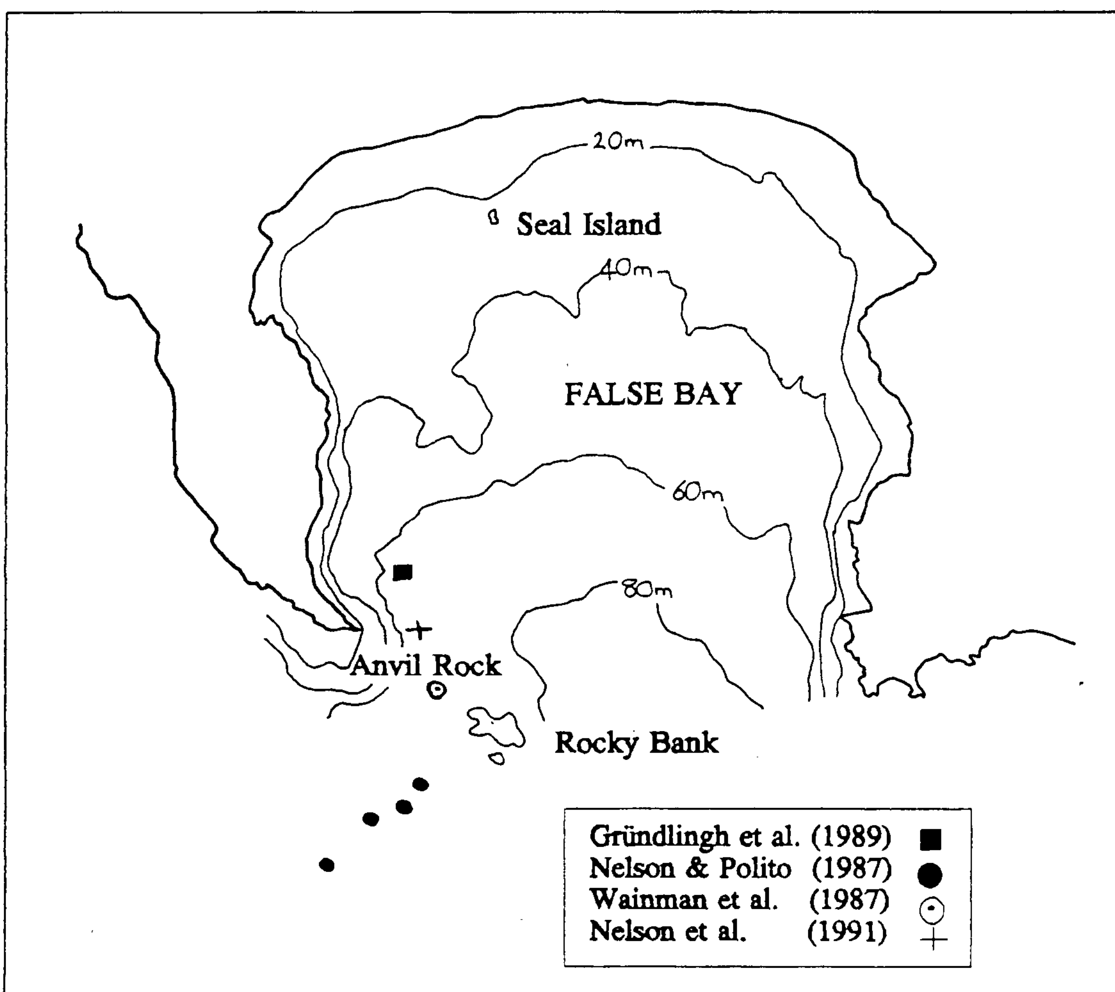

Fig. 7.4: Location of current meter moorings
(After Nelson et al., 1991)

However, the results of all three current meter studies (Wainman et al., 1987; Gründlingh et al., 1989; Nelson et al., 1991) rather than being contradictory, appear to be more consistent with the postulation of Atkins (1970a) that Cape Point may be a separation point where flow from the south-east (under south-easterly wind conditions) is bifurcated, the deflected northern branch giving rise to the observed clockwise circulation in the bay (Fig. 7.5).

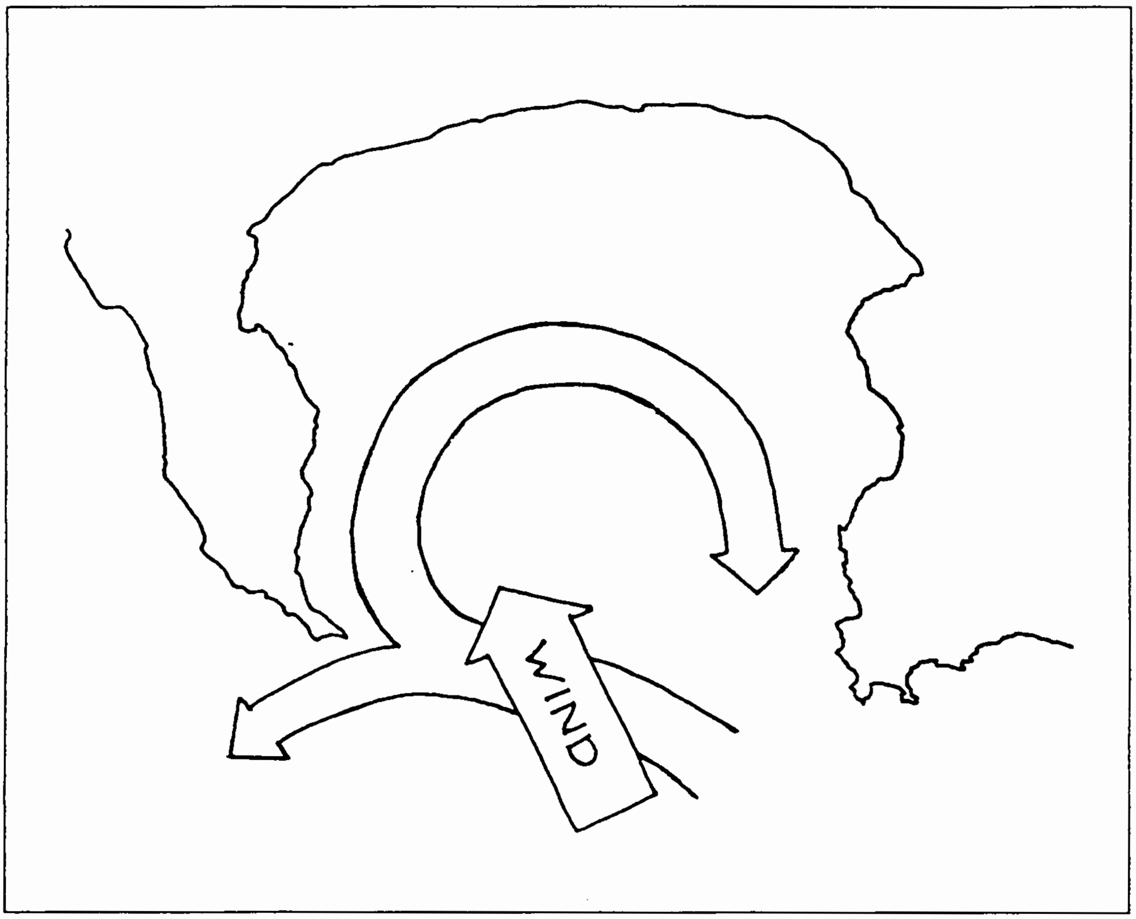

Fig. 7.5: Simplified representation of the cyclonic flow in False Bay created by the bifurcation at Cape Point (After Grundlingh et al., 1989)

Recently a detailed data collection programme, consisting of directly recorded current profiling measurements, drogue trackings and drift cards (see EMATEK, 1991), has further confirmed the surface current patterns postulated by Atkins (1970a). By grouping the surface current patterns together and assigning percentage occurrences to each grouping these results indicated that onshore currents - either directly onshore or with a significant onshore component - occur approximately 20% of the time (because of the relatively high exposure of the bay to southerly winds); offshore currents occur 13% of the time; clockwise or west to east currents, 50% of the time; anticlockwise or east to west currents, 17% of the time.

IMPLICATIONS FOR POLLUTION

It is important to differentiate between the results of Atkins (1970a) and Botes (1988), which present an insight into the surface currents of False Bay (see Fig. 7.1 and 7.2), the depth-averaged circulation predicted by the Van Foreest & Jury (1985) numerical model, and those of Wainman et al. (1987), Gründlingh et al. (1989) and Nelson et al. (1991) which concern the subtidal current variations. This illustrates the multi-layer complexity of the circulation in False Bay and accounts for the apparent lack of consistency between results. Not only do currents vary with depth in the water column, but they also spatially vary across the bay. For convenience, Shannon et al. (1991) in examining the occurrence of colour fronts in False Bay divided the northern bay into four spatial categories (Fig. 7.6) viz.

Area A) Gordon's Bay and the north-eastern corner of False Bay.

Area B) The nearshore zone between the Eerste River and Strandfontein.

Area C) Muizenberg and the north-western corner.

Area D) An extensive tongue-like off-shore area.

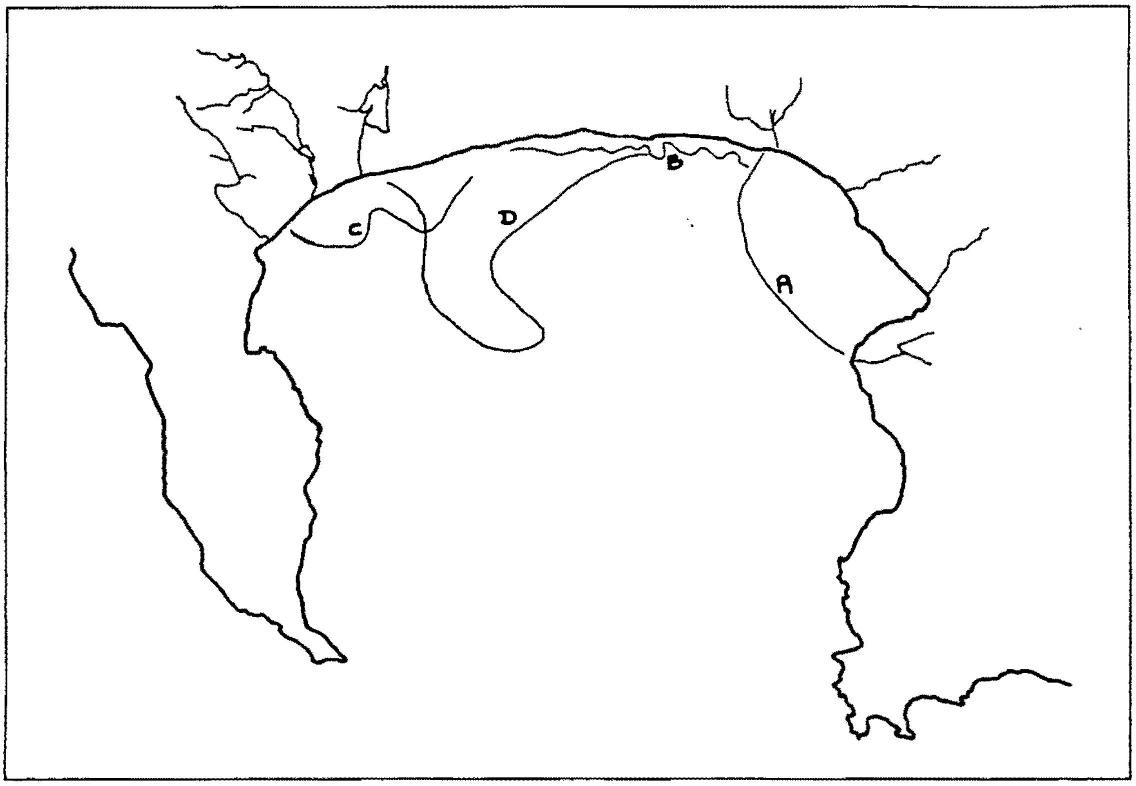

Fig. 7.6: Areas used for spatial categorisation of colour features and fronts (After Shannon et al., 1991)

These categories are based on the wave model of Swart et al. (1987) which showed that the location of discoloured water along the False Bay coast was consistent with the existence of a 'macro-rip' produced by long-shore currents resulting from the focussing of wave energy in different parts of the bay (Shipley (1964) has also shown how the focussing of wave energy by Rocky Bank, at the entrance to the bay, may influence currents). Although Shannon et al. (1991) have shown that the extensive zones of milky coloured water are not pollution related, but are caused by naturally occurring organic material, their spatial categories (A-D, Fig. 7.6) have important implications for pollution. For instance, they report that there is little visual evidence of exchange between nearshore and bay waters in areas A and B, and suggest that the residence time of material in area A may be appreciably long. The principle means of exchange in area B appears to be east to west long-shore currents and they suggest that a major offshore flow can occassionally develop in the vicinity of Strandfontein from wind-induced converging surface currents. This south-westerly curving tongue (area D) occurs mainly in summer, following periods of strong south-east winds, and Shannon et al. (1991) suggest that it would provide a powerful surface transport mechanism for moving material from the surf zone into the central part of the bay, which may be an important source as well as sink for organics and particulates. Since currents transport pollutants and cause them to disperse and mix with unpolluted sea-water, subtidal motions are likely to play a dominant role in transport processes within False Bay. Van Ballegooyen (1991) identifies the following factors as being important to the subtidal response:

i) The morphology of the bay.

ii) Stratification of the water column.

iii) The nature of the forcing.

MORPHOLOGY OF FALSE BAY

The morphology of False Bay has already been described in some detail in Chapter One. Suffice it to say here that the semi-enclosed nature of the bay means that it is exposed to the oceanographical effects from the open ocean outside of the bay, particularly the adjacent continental shelf (see Largier & Swart, 1987; Nelson & Polito, 1987). The result will be a remote forcing effect on the False Bay circulation as well as the forcing by local wind stress over the bay itself (Wainman et al., 1987). Although False Bay forms an integral part of the cold Benguela upwelling regime (Shannon, 1985), rather than that of the wider and warmer Agulhas Bank (Lutjeharms et al., 1991), its surrounding topography substantially modifies the local weather in various parts of the bay (Van Foreest & Jury, 1985), and because of its geography it has an oceanography rather atypical of adjacent areas (Shannon et al., 1991). The northern reaches of the bay consist of an extensive, gently-sloping shallow region in which wave motions and possible tidal flows dominate (Van Ballegooyen, 1991). Water depth gradually increases towards the mouth of the bay and the sea bed slopes steeply up towards the western and eastern coast lines (Fig. 1.2, Chapter One). The steep surrounding topography in the form of the Cape Peninsula Mountain Chain to the west and the Hottentots-Holland Mountains to the east, combined with fairly harsh climatic conditions, produces meteorological conditions that are unique to Southern Africa. Climatological results have indicated that the surrounding mountains exert a channelling and accellerating effect on wind patterns in False Bay (Jury, 1991), and these topographically influenced winds will have an important effect on all physical processes.

THERMAL STRUCTURE

Sea water densities and their variation with water depth are important, as stratification can inhibit mixing of effluent and cause it to be trapped below the sea surface. Although this may be aesthetically advantageous since the effluent is invisible it may, howver, have more insiduous implications for the benthic fauna and flora. There are great seasonal variations in the stratification of the bay waters. Atkins (1970b) identified a significant summer stratification and this has been confirmed by Gründlingh et al. (1989). Results from a current meter deployed near Seal Island (Wainman et al., 1987) indicate flow in nearly opposite directions at 30 metres depth and 19 metres depth. This suggests that the warmer surface water behaves quite differently from the deeper cold water, and that there was considerable shear across the interface. This is surprising as one would expect the water in the shallow northern regions of the bay to remain well mixed throughout the year. However, Gründlingh et al. (1989) report that the waters in fact rapidly restratify after each wind event. A definite seasonal trend in the thermal structure of the water column is evident. Between May and October there is little stratification, but by late December a strong thermocline develops and persists as the summer progresses. Gründlingh et al. (1989) postulate that the advection of colder bottom water and warmer surface water from outside the bay contributes to intensified stratification in summer, as is the case with shelf-current interaction on the South African south coast (Swart & Largier, 1987). Van Ballegooyen (1991) suggests that even if the ambient stratification does not significantly control the dynamics, it remains important in that it may still indirectly affect the qualitative nature of the response.

NATURE OF THE FORCING

Clearly an understanding of the nature of the forcing responsible for the circulation in False Bay is an essential precursor to a conceptual overview of the physical dynamics. Atkins (1970a) postulated that his 'Type 1' current circulation (Fig. 7.1) was probably developed from outside the bay by east and south-easterly winds in the area near Danger Point, with the current then being deflected into False Bay either by angle of approach or by the prevailing south-easterly winds at Cape Point. He suggested that the subsequent circulation pattern was often determined by the direction of entry of the current into the bay. Gründlingh et al. (1989) suggest that the relative shallowness of False Bay and exposure to intense seasonal winds from south-east and north-west lead to a circulation dominated by atmospheric forcing. However, the circulation of False Bay is probably driven by a combination of wind, wave and tidal forcing (Shannon et al., 1991). Certainly, the wide entrance to the ocean makes tidal and wind driven currents important factors in the exchange (Gründlingh et al., 1991).

FLUSHING RATE

As Van Ballegooyen (1991) points out, the relative dominance of remote forcing as against local wind forcing will determine the nature of the flow within False Bay and the exchange of water between False Bay and the adjacent shelf seas. This is crucial in determining the flushing rate, which in turn is of paramount importance to the dispersal of pollutants. The flushing rate of the bay as a whole, and in particular, certain specific areas of it, are of critical importance as far as the pollution of False Bay is concerned. It is therefore more than a little surprising, and of considerable concern, that our estimates of the bay's flushing rates still remain so tenuous. Gründlingh & Largier (1991) point out that the 4-6 day "residence time" estimate of Atkins (1970a) was probably based on the "rotation period" of the bay, and may not be the same as the flushing period of the bay. Gründlingh et al. (1989) have subsequently estimated a flushing rate of 8 days for the upper layer and 11.5 days for the lower layer, based on the results of their study deploying current meters in the lower half of the water column at the entrance to False Bay. However, the authors suggest that their derived estimates should be treated with caution and regarded only as an indication of the flushing rate.

CONCLUSIONS

The complexity of False Bay - its unique topography, bathymetry, meteorology and location - makes it extremely difficult to obtain a true climatic or average circulation of the area. The dynamic nature of the wind stress combined with the varied nature of the forcing interact to produce a complex oceanographical regime. Furthermore, as Gründlingh et al. (1989) point out, all measurements in the bay have been of relatively short duration and conclusions about the steady-state circulation are correspondingly cursory. Despite the amount of research that has take place on False Bay, the lack of a consistent, conceptual overview of the circulation of False Bay is a short-coming that needs to be urgently addressed.

ACKNOWLEDGMENTS

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CHAPTER EIGHT

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The preceding chapters have dealt with some specific aspects of pollution in False Bay, with the emphasis being on the impacts of some individual effluent discharges on the subtidal biota. This chapter summarises and synthesises the main findings of the preceding chapters and examines their implications for the management of False Bay. Recent developments in management strategies for the False Bay area are also discussed, and recommendations made, based on the findings of the individual chapters.

Of the eleven rivers discharging into False Bay none are considered to be in a 'good' condition (see Heydorn, 1986). According to the classification of Heydorn (1986), seven are considered 'poor' (Elsies, Silvermine, Sand, Seekoe, Eerste, Lourens, Sir Lowry's Pass) and four (Buffels West, Steenbras, Rooiels, Buffels East) are considered 'fair'. Most of the river mouths close during the dry summer period except for the Eerste and Seekoe which are kept open by the treated sewage effluent discharged into them. Not only is the use of natural drainage channels as cheap effluent disposal conduits incompatible with sound environmental management (Morant, 1991), but it also profoundly affects the flow regime for which the river originally evolved. The Eerste River is a prime example. Not only does it receive high levels of stormwater from the ever increasing urbanised hard surfaces in its catchment, but much of the treated effluent which is received from various sewage works, originates from water pumped from beyond its catchment (e.g. water pumped from the Theeswater Dam to the Cape Town Metropolitan Area also finds its way into the river). All of this poor quality water eventually ends up in False Bay. Since the burgeoning population of the Greater Cape Town area will demand an increasing volume of water, this problem will be exacerbated, with profound implications for False Bay. It is thus essential that stringent measures are adopted to maintain the water quality entering False Bay. Maximum treatment of the water is necessary before it reaches False Bay because the semi-enclosed nature of the bay renders it unsuitable as a 'sink' for all the contaminated urban run-off from the Greater 'ape Town area. At present this discharge of poor quality stormwater into False Bay is the major pollution threat (see Chapter Two). Various measures should be taken to alleviate the problem. Retention or settling ponds of the type already in use at the Monwabisi outfall (see Plate 2.9, Chapter Two) should be encouraged and extended where possible. These ponds reduce the impact of winter spates on the surf zone by attenuating the hydraulic peaks before they reach False Bay, as well as improving the water quality, since the retention period allows certain natural processes, mainly ultra-violet radiation from sunlight, to reduce bacteriological contamination. The improvement in water quality can be further enhanced by encouraging the growth of filtering plants with their natural purifying functions. Such reed bed nutrient traps or artificial 'wetlands' attract birds of various species (Bickerton, 1982, reported that 22,554 water associated birds of 56 species were counted at the aeration ponds of the Cape Flats Waste Water Treatment Works on a single day) they could be integrated as recreational areas for bird-watchers, hikers and holiday-makers alike. Their close proximity to the sea will be added attraction, particularly if picnic areas were provided. However, more radical measures will in time prove necessary. It is estimated that South Africa will run out water for its population by the year 2020 (B. Davies, pers. Comm.) and therefore water conservation in all forms will be essential. In this regard desalinisation plants should be considered. Not only is this one of the best ways of reusing water but it would also reduce the amount flowing into False Bay. The profligate use of drinking quality water will also need to be re-examined. At present, water of drinking quality is used for all purposes. In future the establishment of different water qualities for different purposes should be considered (Alan Heydorn, pers. comm). It is unnecessary to use drinking quality water for gardening, agriculture and industrial uses, and treated or recycyled water of lower quality would suffice. It is also essential that we endeavour to instill in our population a water conservation ethic through education. We can no longer afford to waste water.

Recently, an encouraging development in this direction has been the establishment of the False Bay Water Quality Committee (FBWQC). This body grew out of the growing public concern and media attention which focused on the deteriorating quality of discharges on the northern shore of False Bay. Established in December 1990, it is the first step towards resolving the fragmented management of False Bay. It is a voluntary organisation comprised of senior officials from the various authorities who have an interest in ensuring that the water quality in False Bay is maintained in the face of increasing development and urbanisation on the periphery of the bay (FBWQC, 1991). This body has made the first successful attempt in co-ordinating the six local authorities, two regional services councils and provincial and Government departments which currently manage the bay and its adjoining catchment areas. The fragmented nature of the False Bay management authorities has always been one of the stumbling blocks in achieving a coordinated policy towards False Bay. The FBWQC has improved communication and co-ordination between concerned local authorities and Government bodies and has already standardised the bacteriological monitoring along the False Bay coast. The European Community directive concerning the quality of bathing water has been adopted to evaluate the water quality entering the bay, and sampling frequency has been increased to once per fortnight in order to meet the requirements of the EEC directive. The spread of sampling stations has been extended to include the relatively unpolluted eastern shoreline in order to give a complete coverage of the bay, and all samples taken by the various local authorities are analyzed in the laboratories of Cape Town Municipality in order to promote standardisation (FBWQC, 1991). This is an extremely positive development since the lack of co-ordination between the various local authorities which have hitherto sampled areas under their jurisdiction has led to haphazard collection of scientific data which has accordingly been of limited value. A co-ordinated monitoring policy will enable any problem areas to be recognised rapidly and action taken to prevent the further pollution of False Bay. The importance of this development cannot be over emphasised. At present the FBWQC is a voluntary body and functions merely in an advisory capacity. It is not an officially constituted body and lacks legislative power. However, in its limited life-span it has proved very successful and should be seriously considered as the framework for the establishment of an officially constituted authority which has the legislative power to holistically manage the bay and its contributing catchment areas.

The ecological value of the rivers flowing into False Bay has been largely neglected. Only the Sand, Eerste, Lourens and Rooiels can be considered as estuaries in terms of Day's (1986) criteria, and even these have been degraded to the extent that their historical importance as nurseries for juvenile fish has declined until they play almost insignificant ecological roles today. In this regard, recent work by Quick & Bennett (1989) indicates that juvenile white Steenbras (Lithognathus lithognathus) are heavily reliant on estuarine nurseries and that Sandvlei may be crucial to the survival of a viable population of white Steenbras in False Bay. Since the estuary mouth is kept closed during the dry summer months in order to maintain water levels for recreation it is thus inaccessible to Lithognathus juveniles during most of their recruitment period (October to March). This highlights the complexity of problems facing management in False Bay because of the conflicting desires of different user groups which tend to take precedence over the ecology. Unless a balanced approach is taken in order to minimise the impacts of user groups on the environment, the value of False Bay as a recreational asset will soon disappear. In this respect, the recent 1991 symposium in Simonstown, held under the auspices of the Western Cape Marine Conservation Society in conjunction with the Wildlife Society of Southern Africa and the Royal Society of South Africa, was an encouraging move in the right direction. The symposium provided a forum for not only scientists. but also for the concerned user groups involved in the False Bay area. These covered a divergent range of interests and included representatives from the Sea Fisheries Research Institute, Environmental Conservation, City Engineers Department, Tourism, Urban and Regional Planning, South African Navy, Kalk Bay fishermen, Trek fishermen, life-saving, surfing, diving, yachting and recreational angling groups. The identification of the various user groups is essential in coordinating an integrated management policy for False Bay. This process is currently under way (Andy Gubb, pers. comm.).

In terms of research, the Sand River has probably been one of the most studied estuaries in False Bay (see Morant & Grindley, 1982; Davies & Stewart, 1984; Stewart & Davies, 1986; Davies et al., 1989; Quick & Bennett, 1989). However further studies and efforts should be made to investigate and retain the few remaining estuarine characteristics of the Eerste, Lourens and Rooiels Rivers as potential fish nurseries. An integrated catchment management policy should be implemented with consultation between the various bodies which control the different catchment areas since most of the water quality problems arise at some distance from the False Bay margins.

Although the discharges of the Steenbras Water Treatment Plant (see Chapters Two and Three) and that of the Marine Oil Refiners near Dido Valley (see Chapter Six) appear to have had no long-term impacts on the subtidal fauna, this is no cause for complacency. Aesthetically both discharges leave something to be desired. Complaints about the plume from the Steenbras Water Treatment Plant outfall in the waters near Gordon's Bay and the floating scum and odour emanating from the Marine Oil Refiners discharge, are commonplace. Cognisance of this should be taken and appropriate action implemented, as such discharges, despite their benign nature, are likely to discourage tourism. With the increased diplomatic initiatives and competitive airfares it is likely that tourism will increase greatly and therefore every effort should be made to preserve an attractive recreational asset such as False Bay. In both the above instances, the simple expedient of constructing a submarine outfall extending further into the bay would more than likely reduce the aesthetically displeasing visible effects from these outfalls.

In terms of plastic pollution (see Chapter Five) it is clear that most of the plastic that finds its way into False Bay is of the packaging type and is left behind by beach-goers. This problem is compounded by the fact that South Africa has a largely Third World population which has access to First World supermarkets. Various approaches are needed to combat the problem of this persistent plastic debris whose effects on marine animals are so lethal (see Chapter Five). The main thrust must be education at grass-roots level combined with more emphasis on recycling and reductions at the production level. In this regard supermarkets should charge a fee for each bag used, as is done in the United Kingdom. This has the definite effect of reducing plastic bag usage, and certainly in terms of False Bay, where plastic bags were the most common form of plastic debris collected (see Chapter Five), it would prove beneficial aesthetically as well as ecologically. In this regard regular beach refuse collections should be maintained and possibly increased.

The higher discharge rates expected in the future, combined with the expected deteriorating discharge quality will lead to further deterioration of sea water quality at the impact areas (EMATEK, 1991). Since most of these discharges take place on the north shore, the circulation patterns are of particular importance (see Chapter Seven). It is ironic that the north shore which poses the greatest pollution threat to False Bay in terms of both quality and volumes of effluents should be the area where their dispersal is the most limited in terms of the physical circulation (see areas A & B, Fig. 7.6, Chapter Seven). In this area the discharges are transported along the coastline for long distances and remain trapped in the surf-zone. Since strong onshore winds usually prevail in the summer, when most holiday-makers are using the recreational facilities on the False Bay coastline, the problem of effluent discharge on the north shore is further compounded. Fortunately the greater stormwater flows occur in the winter months when there is a greatly reduced demand on the recreational facilities. Although this puts bathers at less risk, as Gründlingh et al. (1991) report, the current speeds decrease significantly during the summer months and the bay appears to become more stagnant during the winter. This has serious implications for the dispersal of stormwater, since the highest loadings occur during winter spates. At present, estimates of the bay's flushing rate are tenuous at best, and no research has been done on the differences between winter and summer flushing rates. Since by far the greatest flows of contaminated urban run-off enter the bay during winter, this gap in our knowledge should be urgently addressed.

In terms of the conservation status of the bay there are only a few small sections of the False Bay coastline which enjoy varying levels of protection viz.

i) Neptune's Corner to St. James.

ii) St. James to Kalk Bay Harbour wall.

iii) Fish Hoek to Glencairn.

iv) Castle Rocks marine reserve (this extends from Bakhoven Rock near Miller's Point to Baboon Rock, near Smitswinkel Bay).

v) Gordon's Bay Harbour to the Lourens River mouth.

Besides these officially protected areas, the area between the Lourens River and the Eerste River, which falls under the auspices of AECI and SOMCHEM, has restricted access. The remainder of the False Bay coastline is subject only to the normal restrictions applicable to the coastline in general. Van Herwerden (1989) noted on numerous occasions that people were exploiting both intertidal and subtidal organisms in the conservation areas of False Bay due to poor enforcement of conservation regulations. During a three year study Van Herwerden & Griffiths (1991) found no clear change or recovery of intertidal communities within the reserves and attributed this to the incomplete conservation of the area. Thus conservation strategy should be well defined and the legislation enforceable, otherwise conservation policy becomes ineffective. At present there are only five to six conservation enforcement officers for the whole of False Bay (Vic Kabalin, pers. comm). Clearly this is inadequate for such a huge area and more efficient methods of policing and monitoring the dwindling marine resources of the bay should be implemented. Edible species such as crayfish (Jasus lalandii) and perlemoen (Haliotis midae) of legal size are very difficult to find in most areas of the bay and both the numbers and size of Alikreukal (Turbo sarmaticus) have been reduced in most accessible areas were they are regularly collected. Hence selected species are certainly being affected by exploitation. Fortunately, levels of subsistence exploitation are presently negligible (Van Herwerden & Griffiths, 1991) compared to places such as the Transkei (Seigfried et al., 1985; Hockey & Bosman, 1986; Branch & Shackleton, 1988; Hockey et al., 1988), but are likely to increase in the future as a result of the burgeoning informal settlements on the north shore. Field (1970) identified five benthic invertebrate communities in False Bay: one close inshore on the northern shallows, two in intermediate depths in north-east and north-west corners, a fourth near the centre of bay and a fifth at the centre of the mouth. Branch (1980) suggests that the complex hydrology and geology and the occurence of discreet benthic communities in different regions emphasises the heterogeneity of the bay and the fact that piecemeal protection of a small section of the bay will not be a satisfactory long term solution to the conservation of the area. Although the idea of turning the whole of the bay into a marine reserve has often been mooted, Siegfried & Davies (1982) suggest that when designing marine reserves the advantages of having one large permanent reserve should be weighed up against having a series of smaller reserves at different locations in different years. In South Africa, the anomalous situation exists whereby common law excludes the coastal area below the high water mark from proclaimed terrestial nature reserves. In False Bay, this means that the shoreline of the Cape Point Nature Reserve enjoys no protection of its marine resources. Marine, coastal and terrestial environments are interdependent and need to be managed as such. Managers need to comprehend that the ecosystem extends beyond the immediate environment of the bay since many mammals and birds depend for their survival on routine utilisation of both terrestrial and marine areas of the bay environment. The management of False Bay should be based on the recognition and understanding of whole ecosystems with their appropriate geographical realms, as opposed to managing fragments of systems or arbitrarily identified areas of land or water (Siegfried, 1980). Hockey & Buxton (1989) suggest that only if authority for the protection of the seashore in South Africa is altered, so that nature reserves on the coast are extended seawards, will adequate conservation be achieved along much of the South African coastline. The present controversy concerning a housing development at Silvermine (see Argus 10.06.92; 12.06.92; 13.06.92.) highlights the necessity of achieving a balance between development and conservation. Fortunately, the South African Council for the Environment, in its policy for coastal zone management, has recently brought out comprehensive guidelines for coastal land use. These should be mandatory for all developments along the South African coastline.

Although the first tentative steps towards an integrated False Bay management have been taken with the establishment of the False Bay Water Quality Committee, it is important that the momentum be maintained. An officially constituted body with legislative power is needed if holistic management of the bay is to be achieved. An overall management policy for False Bay, and its environs, needs to be urgently formulated. This policy should provide the controls and guidelines for the numerous user groups, have an integrated and enforceable conservation policy for the maintainence of the bay's natural resources, establish a committee to co-ordinate scientific research in the bay, and generally ensure that the bay's attractions are preserved for future generations.

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APPENDICES

APPENDIX ONE - ACKNOWLEDGEMENTS

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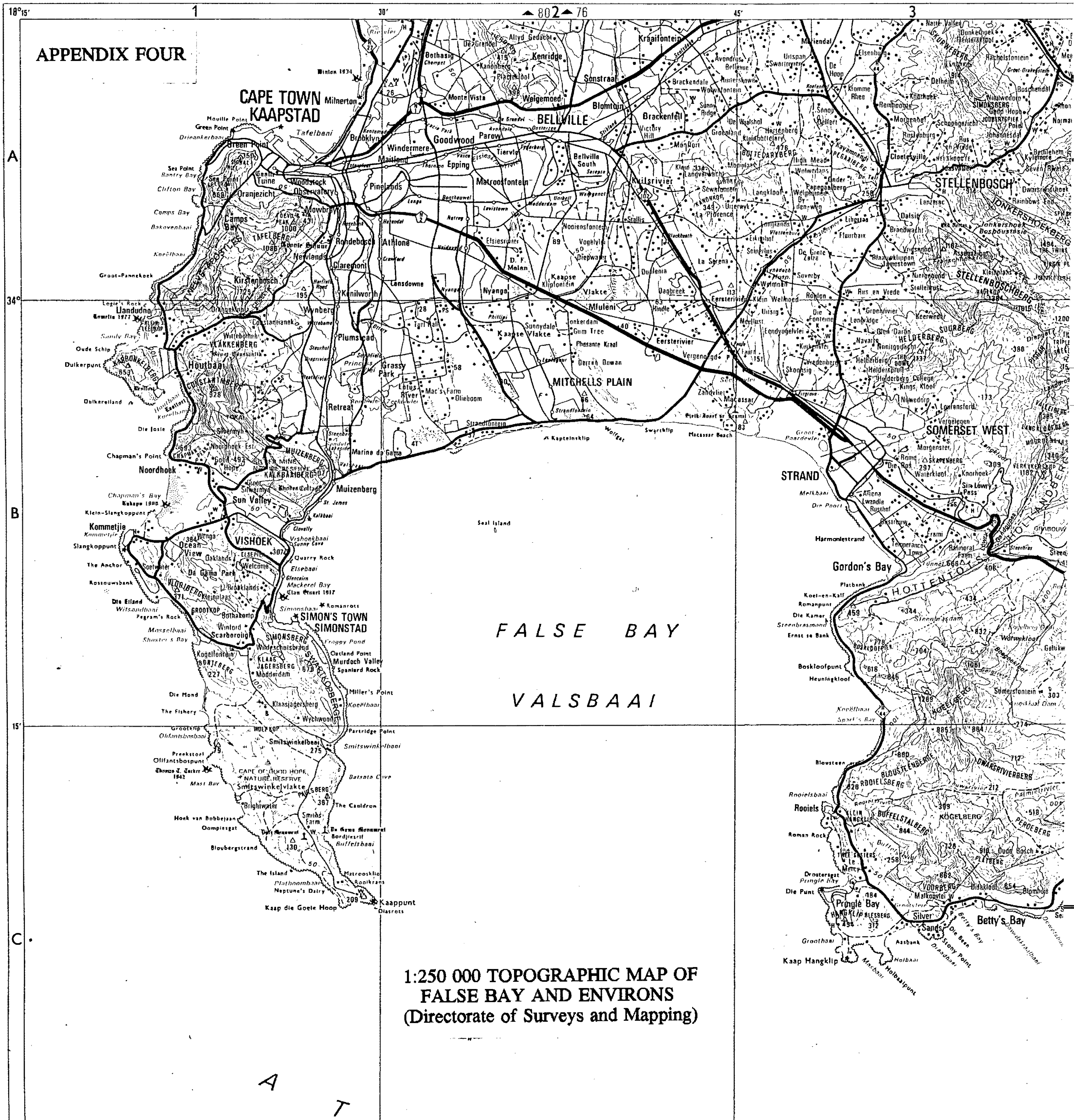
APPENDIX THREE - FALSE BAY MANAGEMENT AND ENVIRONMENTAL BODIES

Council for the Environment	Private Bag X447 Pretoria 0001 South Africa
False Bay Water Quality Committee	City Engineer's Department P.O. Box 1694 Cape Town 8000 South Africa
Earth, Marine & Atmospheric Science and Technology	P.O. Box 320 Stellenbosch 7600 South Africa
Dolphin Action and Protection Group	P.O. Box 22227 Fish Hoek 7975 South Africa
Wildlife Society of Southern Africa (Western Cape Branch)	P.O. Box 30145 Tokai 7966 South Africa
South African National Foundation for the Conservation of Coastal Birds	P.O. Box 11116 Bloubergrant 7443 South Africa
Royal Society of South Africa	P.O. Box 594 Cape Town 8000 South Africa

APPENDIX FOUR



1:250 000 TOPOGRAPHIC MAP OF
FALSE BAY AND ENVIRONS
(Directorate of Surveys and Mapping)